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The calculation of reinforced concrete bridges consisting of three sections on four piers,

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Figs. 1 to 24, pp. 639 to 663.

An article published in Nos. 1, 2, and 3 of the *Bulletin Technique de l'Union des Ingénieurs de Louvain*, 1925, by Mr. F. Berger dealt in particular with the calculation of the stresses in a bridge of the form shown in figure 1.

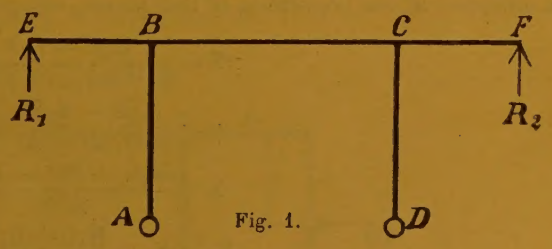


Fig. 1.

The present note deals with the rather more complicated type of structure characterised by the bearings E and F being lowered to H and K by means of two new piers resulting in the design shown in figure 2.

It will be remembered the calculations are based on the following principles : the middle of the span BC is cut at G as shown in figure 3 and a moment μ, a vertical load X, and a horizontal load S are supposed to act thereat.

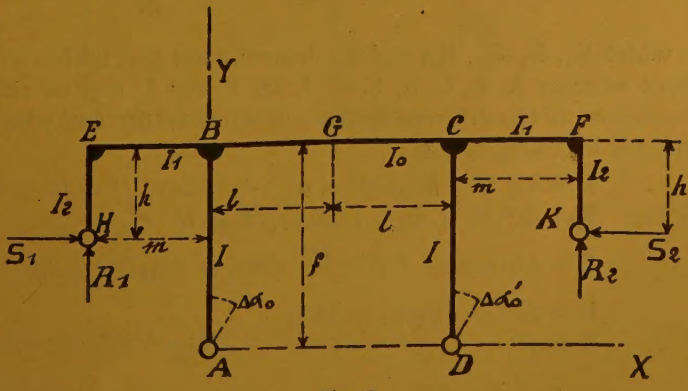


Fig. 2.

If we can determine μ, S, X for each type of loading of the structure, the problem of finding the stresses at each point of the bridge will be solved.

We will suppose that the moments of inertia of the different sections have the following values : I_0 from B to C, I from A to B and from D to C, I_1 from B to E and from C to F, and I_2 from E to H and from F to K; we can also take

$$\frac{I_0}{I} = t, \frac{I_0}{I_1} = t_1, \text{ and } \frac{I_0}{I_2} = t_2.$$

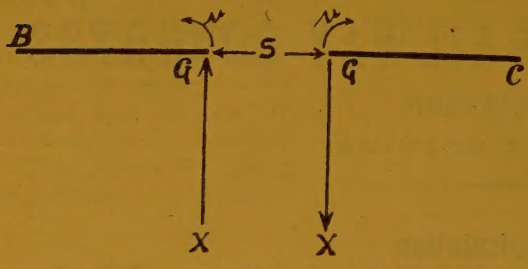


Fig. 3.

It will also be remembered that the angular variations $\Delta\alpha_0$ and $\Delta\alpha'_0$ are taken as occuring at A and D respectively, that sinking occurs at A, H and K to the numerical value of Δy_a, d, and d', that movement towards the left takes place at A, H and K having the numerical values Δx_a, c and c', that the live loads considered only act on the left hand section GBAEH, and that the horizontal and vertical reactions S_1, S_2, R_1 and R_2 act at H, and K; finally that expansion or contraction $\pm 2\lambda$ affect the section BC and that there were reinforcements at B, C, E and F as shown in the sketch so that a sufficiently large radius of curvature can be supposed between the points for the formulæ of deflection of curved members to be used.

Having obtained and solved a system of nine equations similar to those in the article mentioned at the beginning of this paper, wet get :

$$S = \frac{K_1 A - K_2 B}{2f^2 h^2 m t_1 C (2f + h)} \quad \ldots\ldots\ldots \quad (710)$$

$$\mu = \frac{K_1 D - K_2 E}{2fhC(2f + h)} \quad \ldots\ldots\ldots \quad (711)$$

$$X = \frac{H_4 G + H_5 J - L M_A}{2l^2 N} \quad \ldots\ldots\ldots \quad (712)$$

$$S_1 - S_2 = \frac{H_4 O + H_5 V - U M_A}{lN} \quad \ldots\ldots\ldots \quad (713)$$

in which K_1, K_2, H_4, H_5, and M_A depend upon the particular state of loading considered whereas A, B, C, D, E, G, J, O, V and U depend solely upon the form and dimensions of the different sections of the structure and when calculated once for all have the following values :

$$A = 4(f^3 t + h^3 t_2)(3l + mt_1) + 12\, lmt_1 (f^2 + fh + h^2) + 3h^2 m^2 t_1^2 \quad (714)$$

$$B = 2f^3 t(3l + mt_1) + 3flmt_1 (2f + h) \quad \ldots\ldots\ldots \quad (715)$$

$$C = 4ftl(mt_1 + ht_2) + \frac{mt_1}{3}(3mt_1 + 4ht_2)(ft + 3l) \quad \ldots\ldots\ldots \quad (716)$$

$$D = 2f^2 t - h(3mt_1 + 4ht_2) \quad \ldots\ldots\ldots \quad (717)$$

$$E = f^2 t \quad \ldots\ldots\ldots \quad (718)$$

$$G = 12\,[f^3 t + h^3 t_2 + m t_1 (f^2 + fh + h^2)]. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (719)$$

$$J = 6 l m t_1 (2f + h). \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (720)$$

$$L = l m t_1 [f^2 t (2f + 3h) - h^2 (3 m t_1 + 4 h t_2)] \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (721)$$

$$N = 4 (f^3 t + h^3 t_2) (l + m t_1) + m t [4 l (f^2 + h^2 + fh) + 3 h^2 m t_1]. \quad . \quad . \quad (722)$$

$$O = 6 m t_1 (2f + h) = \frac{J}{l} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (723)$$

$$V = 12 l (l + m t_1) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (724)$$

$$U = 2 l [3 f^2 t (l + m t_1) + l m t_1 (2f + h)] \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (725)$$

The values of $(S_1 + S_2)$, $(R_1 + R_2)$, $(R_1 - R_2)$ will be found from the following formulæ respectively :

$$S_1 + S_2 = \frac{4 f m t_1 S + 4 \mu (3 l + m t_1) - 2 (3 H_1 + m t_1 M_A)}{m t_1 (2f + h)} \quad . \quad . \quad . \quad (726)$$

$$R_1 + R_2 = \frac{- 12 l \mu + 3 h m t_1 (S_1 + S_2) + 6 H_1}{2 m^2 t_1} \quad . \quad . \quad . \quad . \quad . \quad . \quad (727)$$

$$R_1 - R_2 = \frac{2 l X - (S_1 - S_2)(f - h) - M_A}{m} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (728)$$

In all formulæ 726 to 728, H_1 also depends upon the state of loading of the structure. (729)

Applying the above results to the various particular cases of loading we get :

First case. — Local vertical load P_1 acting on the section BG at a horizontal distance a from B, a being $\leqslant l$ (see fig. 4) :

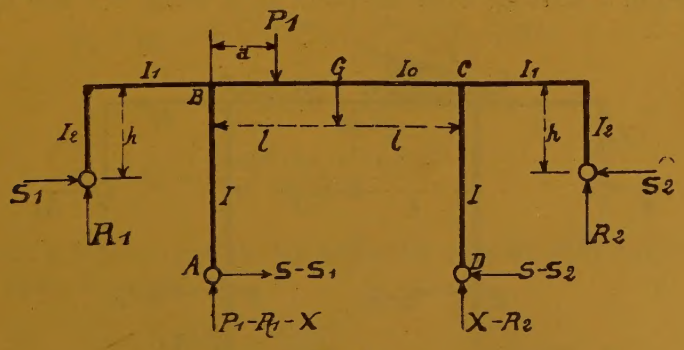


Fig. 4.

If we take :

$$\alpha_1 = m t_1 [(3 m t_1 + 4 h t_2) h - 2 f^2 t] \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (740)$$

$$\alpha_2 = f t m t_1 \left(\frac{4}{3} h t_2 + m t_1\right) . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (741)$$

$$\alpha_3 = m t_1 \left(2 f t + \frac{3}{2} m t_1 + 2 h t_2\right) + 2 f t h t_2 \quad . \quad . \quad . \quad . \quad . \quad . \quad (742)$$

$$\alpha_4 = lmt_1[4f^3t + h^2(3mt_1 + 4ht^2)] \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (743)$$

$$\alpha_5 = 2[f^3t + h^3t_2 + mt_1(f^2 + fh + h^2)] \quad . \quad . \quad . \quad . \quad . \quad (744)$$

$$\alpha_6 = [2(f^3t + h^3t_2) + 3hmt_1(f + h)] \quad . \quad . \quad . \quad . \quad . \quad . \quad (745)$$

We find :

$$S = \frac{\alpha_1 P_1 a (2l - a)}{4fhC} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (746)$$

$$\mu = \frac{P_1 a (\alpha_2 + \alpha_3 a)}{2C} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (747)$$

$$X = \frac{P_1 a [\alpha_4 + \alpha_5 a (3l - a)]}{2l^2 N} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (748)$$

$$S_1 + S_2 = \frac{-P_1 a (2l - a) ftmt_1}{B.C} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (749)$$

$$R_1 + R_2 = \frac{-P_1 a (2l - a) f^t (3mt_1 + 2ht_2)}{mC} \quad . \quad . \quad . \quad . \quad . \quad (750)$$

$$S_1 - S_2 = \frac{-P_1 a (l - a) (2l - a) mt_1 (2f + h)}{lN} \quad . \quad . \quad . \quad . \quad . \quad (751)$$

$$R_1 - R_2 = \frac{-\alpha_6 P_1 a (l - a) (2l - a)}{lmN} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (752)$$

The accuracy of these simple formulæ can be easily checked by taking $a = 0$, and $a = l$ successively. For example when $a = l$, $X = \frac{P_1}{2}$.

Second case. — Distributed vertical loading varying from p_1 to p_2, on a horizontal length a starting from the point B, a being $\leqslant l$ (see fig. 5).

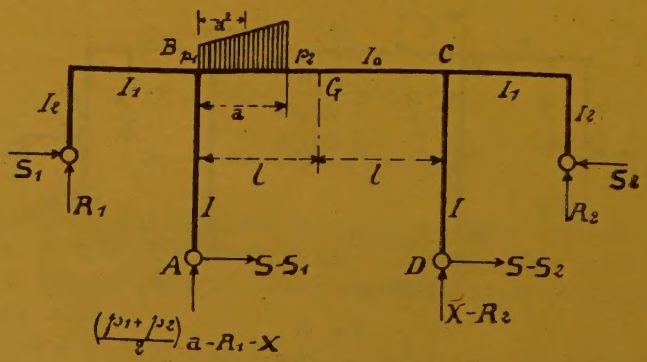


Fig. 5.

Noting that α_1, α_2, α_3, α_4, α_5, and α_6 have the same values as in formulæ (740) to (745), we get :

$$S = \frac{\alpha_1 a^2 [p_1 (4l - a) + p_2 (8l - 3a)]}{48fhC} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (753)$$

$$\mu = \frac{a^2\,[p_1(2\alpha_2 + \alpha_3 a) + p_2(4\alpha_2 + 3\alpha_3 a)]}{24C} \quad \ldots \quad (755)$$

$$X = \frac{a^2\}\,p_1[10\alpha_4 + 3\alpha_5 a(5l - a)] + p_2[20\alpha_4 + 3\alpha_5 a(15l - 4a)]\{}{120l^2N} \quad \ldots \quad (756)$$

$$S_1 + S_2 = \frac{-a^2 ftmt_1\,[p_1(4l - a) + p_2(8l - 3a)]}{12hC} \quad \ldots \quad (757)$$

$$R_1 + R_2 = \frac{-a^2 ft(3mt_1 + 2ht_2)\,[p_1(4l - a) + p_2(8l - 3a)]}{12mC} \quad \ldots \quad (758)$$

$$S_1 - S_2 = \frac{-a^2 mt_1(2f + h)\,[p_1(20l^2 - 15al + 3a^2) + p^2(40l^2 - 45al + 12a^2)]}{60lN} \quad (759)$$

$$R_1 - R_2 = \frac{-\alpha_6 a^2\,[p_1(20l^2 - 15al + 3a^2) + p_2(40l^2 - 45al + 12a^2)]}{60lmN} \quad \ldots \quad (760)$$

In the particular case when $a = l$:

$$S = \frac{\alpha_1 l^3(3p_1 + 5p_2)}{48fhC} \quad \ldots \quad (761)$$

$$\mu = \frac{l^2\,[p_1(2\alpha_2 + \alpha_3 l) + p_2(4\alpha_2 + 3\alpha_3 l)]}{24C} \quad \ldots \quad (762)$$

$$X = \frac{2p_1(5\alpha_4 + 6\alpha_5 l^2) + p_2(20\alpha_4 + 33\alpha_5 l^2)}{120N} \quad \ldots \quad (763)$$

$$S_1 + S_2 = \frac{-l^3 ftmt_1(3p_1 + 5p_2)}{12hC} \quad \ldots \quad (764)$$

$$R_1 + R_2 = \frac{-l^3 ft(3mt_1 + 2ht_2)(3p_1 + 5p_2)}{12mC} \quad \ldots \quad (765)$$

$$S_1 - S_2 = \frac{-l^3 mt_1(2f + h)(8p_1 + 7p_2)}{60N} \quad \ldots \quad (766)$$

$$R_1 - R_2 = \frac{-\alpha_6 l^3(8p_1 + 7p_2)}{60mN} \quad \ldots \quad (767)$$

If in addition $p_1 = p_2$, *i. e.* if the left half of the span BC is uniformly loaded by p_1 as shown in figure 6, we get :

$$S = \frac{\alpha_1 p_1 l^3}{6fhC} \quad \ldots \quad (768)$$

$$\mu = \frac{p_1 l^2(3\alpha_2 + 2\alpha_3 l)}{12C} \quad \ldots \quad (769)$$

$$X = \frac{p_1(2\alpha_4 + 3\alpha_5 l^2)}{8N} \quad \ldots \quad (770)$$

$$S_1 + S_2 = \frac{-2p_1 l^3 ftmt_1}{3hC} \quad \ldots \quad (771)$$

$$R_1 + R_2 = \frac{-2p_1 l^3 ft\,(3mt_1 + 2ht_2)}{3mC} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (772)$$

$$S_1 - S_2 = \frac{-p_1 l^3 mt_1\,(2f + h)}{4N} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (773)$$

$$R_1 - R_2 = \frac{-\alpha_6 p_1 l^3}{4mN} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (774)$$

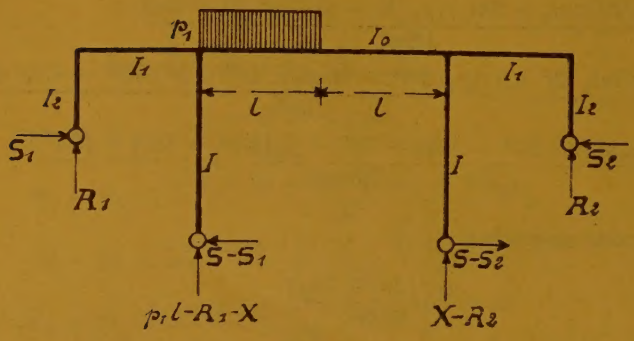


Fig. 6.

THIRD CASE. — Local horizontal load P_3 acting on the pier AB at a distance b from A (see fig. 7).

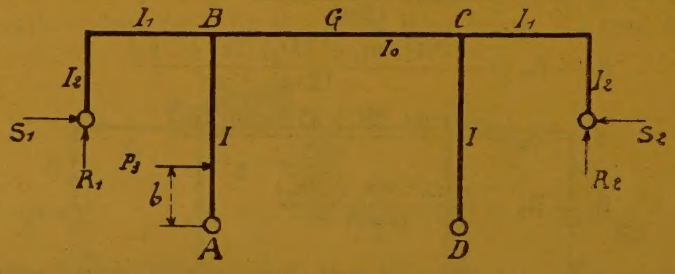


Fig. 7.

If we take :

$$\gamma_1 = 3f\,[(3mt_1 + 4ht_2)\,(ft + 2l)\,mt_1 + 2ftl\,(6h^2t_2 + fmt_1 + 6hmt_1)] \quad . \quad (781)$$

$$\gamma_2 = t\,[h\,(3mt_1 + 4ht_2)\,(mt_1 + 3l) + 3lmt_1\,(2f + h)] \quad . \quad . \quad . \quad . \quad . \quad (782)$$

$$\gamma_3 = tmt_1\,(3mt_1 + 4ht_2) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (783)$$

$$\gamma_4 = mt_1\,[h^2\,(3mt_1 + ht_2) - f^2 t\,(2f + 3h)] \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (784)$$

$$\gamma_5 = tmt_1\,(2f + h) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (785)$$

$$\gamma_6 = tl\,(3mt_1 + 2ht_2) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (786)$$

$$\gamma_7 = 2\,[lmt_1\,(2f + h) + 3f^2 t\,(l + mt_1)] \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (787)$$

$$\gamma_8 = 2t\,(l + mt_1) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (788)$$

$$\gamma_9 = 2l\,(f^3t - 2h^3t_2) - 3f^2th\,(2l + 3mt_1) - 3hmt_1\,[2l\,(f + h) + h^2t_2] \quad . \quad (789)$$

$$\gamma_{10} = t\,[3hmt_1 - 2l\,(f - h)] \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (790)$$

We get :

$$S = \frac{P_3 b\,(\gamma_1 - \gamma_2 b^2)}{12 f^2 hC} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (791)$$

$$\mu = \frac{-\gamma_3 P_3 b\,(f^2 - b^2)}{12 fC} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (792)$$

$$X = \frac{P_3 b\,(\gamma_4 + \gamma_5 b^2)}{2fN} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (793)$$

$$S_1 + S_2 = \frac{P_3 btlmt_1\,(f^2 - b^2)}{fhC} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (794)$$

$$R_1 + R_2 = \frac{P_3 b\gamma_6\,(f^2 - b^2)}{fmC} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (795)$$

$$S_1 - S_2 = \frac{P_3 b\,(\gamma_8 b^2 - \gamma_7)}{N} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (796)$$

$$R_1 - R_2 = \frac{P_3 b\,(\gamma_9 + \gamma_{10} b^2)}{mN} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (797)$$

The accuracy of these simple formulæ can be easily checked by taking $b = 0$ and $b = f$ in turn : for example when $b = f$: $S = \frac{P_3}{2}$, $\mu = 0$, $S_1 + S_2 = 0$, $R_1 + R_2 = 0$.

Fourth case. — Horizontal load varying from p_3 to p_4 distributed over a vertical length b above A (see fig. 8) :

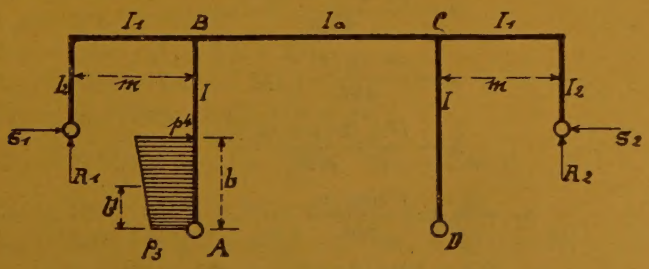


Fig. 8.

Noting that formulæ 781 to 790 giving the values of γ_1 to γ_{10} remain unchanged, we get :

$$S = \frac{b^2\,[p_3\,(10\gamma_1 - 3\gamma_2 b^2) + 4p_4\,(5\gamma_1 - 3\gamma_2 b^2)]}{720 f^2 hC} \quad . \quad . \quad . \quad . \quad (798)$$

$$\mu = \frac{-\gamma_3 b^2 [p_3 (10f^2 - 3b^2) + 4p_4 (5f^2 - 3b^2)]}{720fC} \quad . \quad . \quad . \quad . \quad (799)$$

$$X = \frac{b^2 [p^3 (10\gamma_4 + 3\gamma_5 b^2) + 4p_4 (5\gamma_4 + 3\gamma_5 b^2)]}{120lN} \quad . \quad . \quad . \quad . \quad (800)$$

$$S_1 + S_2 = \frac{b^2 tlmt_1 [p_3 (10f^2 - 3b^2) + 4p_4 (5f^2 - 3b^2)]}{120fhC} \quad . \quad . \quad . \quad . \quad (801)$$

$$R_1 + R_2 = \frac{\gamma_6 b^2 [p_3 (10f^2 - 3b^2) + 4p_4 (5f^2 - 3b^2)]}{60fmC} \quad . \quad . \quad . \quad . \quad (802)$$

$$S_1 - S_2 = \frac{b^2 [p_3 (3\gamma_8 b^2 - 10\gamma_7) + 4p_4 (3\gamma_8 b^2 - 5\gamma_7)]}{60N} \quad . \quad . \quad . \quad . \quad (803)$$

$$R_1 - R_2 = \frac{b^2 [p_3 (10\gamma_9 + 3\gamma_{10} b^2) + 4p_4 (5\gamma_9 + 3\gamma_{10} b^2)]}{60mN} \quad . \quad . \quad . \quad . \quad (804)$$

These formulæ can be easily simplified in the case when $b = f$.

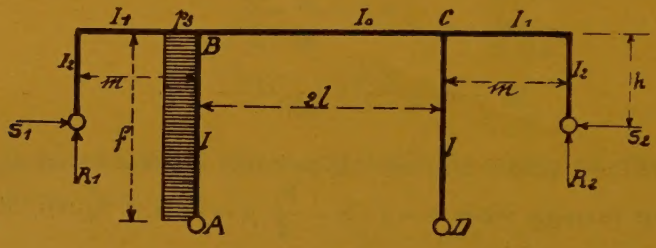


Fig. 9.

If in addition to making $b = f$, we take $p_3 = p_4$, we get (see fig. 9) :

$$S = \frac{p_3 (2\gamma_1 - \gamma_2 f^2)}{48hC} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (805)$$

$$\mu = \frac{-\gamma_3 f^3 p^3}{48C} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (806)$$

$$X = \frac{f^2 p_3 (2\gamma_4 + \gamma_5 f^2)}{8lN} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (807)$$

$$S_1 + S_2 = \frac{f^3 tlmt_1 p_3}{8hC} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (808)$$

$$R_1 + R_2 = \frac{\gamma_6 f^3 p_3}{4mC} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (809)$$

$$S_1 - S_2 = \frac{f^2 p_3 (\gamma_8 f^2 - 2\gamma_7)}{4N} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (810)$$

$$R_1 - R_2 = \frac{f^2 p_3 (2\gamma_9 + \gamma_{10} f^2)}{4mN} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (811)$$

FIFTH CASE. — Local vertical load P_5 acting at a horizontal distance d to the left of B (see fig. 10) :

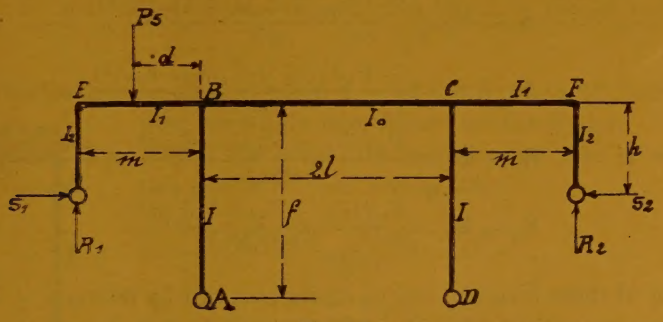


Fig. 10.

If we take :

$$\delta_1 = lm^2t_1\,[h\,(3mt_1 + 4ht_2) - 2f^2t] \quad (818)$$
$$\delta_2 = mt_1\,[lmt_1\,(ft + 3l) + 6lh\,(mt_1 + ht_2)] \quad (819)$$
$$\delta_3 = t_1\,[fmt_1\,(ft + 3l) + lh\,(3mt_1 + 2ht_2) + 2f^2lt] \quad (820)$$
$$\delta_4 = fltt_1m^2\,(3mt_1 + 4ht_2) \quad (821)$$
$$\delta_5 = 6ftmt_1\,(mt_1 + ht_2) \quad (822)$$
$$\delta_6 = fltt_1\,(3mt_1 + 2ht_2) \quad (823)$$
$$\delta_7 = m^2t_1\,(4f^3t + 4h^3t_2 + 3h^2mt_1) \quad (824)$$
$$\delta_8 = 3mt_1\,[2f^3t + 2h^3t_2 + hmt_1\,(f + 2h)] \quad (825)$$
$$\delta_9 = t_1\,[2f^3t + 2h^3t_2 + 3hmt_1\,(f + h)] \quad (826)$$
$$\delta_{10} = 2lm^2t_1\,(2f + h) \quad (827)$$
$$\delta_{11} = 3mt_1\,(hmt_1 - 2fl) \quad (828)$$
$$\delta_{12} = t_1\,(2lh - 2lf + 3hmt_1) \quad (829)$$
$$\delta_{13} = 2ftlm^2t_1 \quad (830)$$
$$\delta_{14} = m^2t_1^2\,(ft + 3l) \quad (831)$$
$$\delta_{15} = t_1\,[mt_1\,(ft + 3l) + 2ftl] \quad (832)$$
$$\delta_{16} = 2ftlmt_1\,(3mt_1 + 2ht_2) \quad (833)$$
$$\delta_{17} = mt_1^2\,(3mt_1 + 2ht_2)\,(ft + 3l) \quad (834)$$
$$\delta_{18} = 2t_1^2\left[ft\left(mt_1 + l + \frac{ht_2}{3}\right) + l\,(ht_2 + 3mt_1)\right] \quad (835)$$
$$\delta_{19} = 2lmt_1\,[2\,(f^3t + h^3t_2) + 3hmt_1\,(f + h)] \quad (836)$$
$$\delta_{20} = 3m^2t_1^2\,[2\,(f^3t + h^3t_2) + 3h^2mt_1 + 2fl\,(l - h)] \quad (837)$$
$$\delta_{21} = 2t_1^2\,[f^3t + h^3t_2 + 3h^2mt_1 + l(f - h)^2].$$

We find :

$$S = \frac{-P_5d\,(\delta_1 - \delta_2d + \delta_3d^2)}{2fhmC} \quad (838)$$

$$\mu = \frac{-P_5d\,(\delta_4 - \delta_5d + \delta_6d^2)}{6mC} \quad (839)$$

$$X = \frac{-P_5 d\,(\delta_7 - \delta_8 d + \delta_9 d^2)}{2lmN} \quad . \quad . \quad . \quad . \quad . \quad . \quad (840)$$

$$S_1 - S_2 = \frac{P_5 d\,(\delta_{10} + \delta_{11} d - \delta_{12} d^2)}{mN} \quad . \quad . \quad . \quad . \quad . \quad (841)$$

$$S_1 + S_2 = \frac{-P_5 d\,(\delta_{13} + \delta_{14} d - \delta_{15} d^2)}{mhC} \quad . \quad . \quad . \quad . \quad . \quad (842)$$

$$R_1 + R_2 = \frac{P_5 d\,(\delta_{16} + \delta_{17} d - \delta_{18} d^2)}{m^2 l_1 C} \quad . \quad . \quad . \quad . \quad . \quad (843)$$

$$R_1 - R_2 = \frac{P_5 d\,(\delta_{19} + \delta_{20} d - \delta_{21} d^2)}{m^2 l_1 N} \quad . \quad . \quad . \quad . \quad . \quad (844)$$

The accuracy of these formulæ can be easily checked by taking $d = 0$ and $d = m$; in the latter case we ought to find $R_1 = P_5$, $\mu = 0$, $S = 0$, $X = 0$.

Sixth case. — Distributed vertical load varying from p_5 to p_6 on a horizontal length d taken to the left from the point B (see fig. 11).

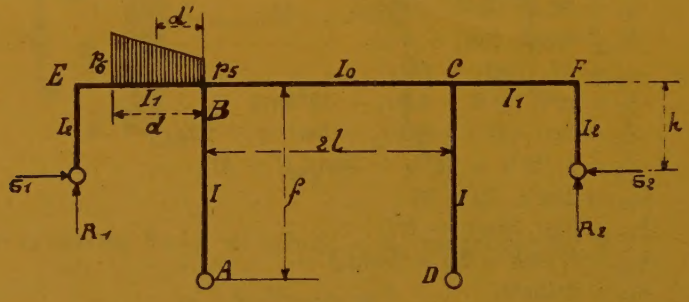


Fig. 11.

As formulæ (818) to (837) giving the values of δ_1 to δ_{20} remain unchanged, we get :

$$S = \frac{-d^2\,[p_5\,(10\delta_1 - 5\delta_2 d + 3\delta\, d^2) + p_6\,(20\delta_1 - 15\delta_2 d + 12\delta_3 d^2)]}{120 lhmC} \quad . \quad (845)$$

$$\mu = \frac{-d^2\,[p_5\,(10\delta_4 - 5\delta_5 d + 3\delta_6 d^2) + p_6\,(20\delta_4 - 15\delta_5 d + 12\delta_6 d^2)]}{360 mC} \quad . \quad (846)$$

$$X = \frac{-d^2\,[p_5\,(10\delta_7 - 5\delta_8 d + 3\delta_9 d^2) + p_6\,(20\delta_7 - 15\delta_8 d + 12\delta_9 d^2)]}{120 lmN} \quad . \quad (847)$$

$$S_1 - S_2 = \frac{d^2\,[p_5\,(10\delta_{10} + 5\delta_{11} d - 3\delta_{12} d^2) + p_6\,(20\delta_{10} + 15\delta_{11} d - 12\delta_{12} d^2)]}{60 mN} \quad (848)$$

$$S_1 + S_2 = \frac{-d^2\,[p_5\,(10\delta_{13} + 5\delta_{14} d - 3\delta_{15} d^2) + p_6\,(20\delta_{13} + 15\delta_{16} d - 12\delta_{17} d^2)]}{60 mhC} \quad (849)$$

$$R_1 + R_2 = \frac{d^2\,[p_5\,(10\delta_{16} + 5\delta_{17}d - 3\delta_{18}d^2) + p_6\,(20\delta_{16} + 15\delta_{17}d - 12\delta_{18}d^2)]}{60m^2t_1C} \quad (850)$$

$$R_1 - R_2 = \frac{d^2\,[p_5\,(10\delta_{19} + 5\delta_{20}d - 3\delta_{21}d^2) + p_6\,(20\delta_{19} + 15\delta_{20}d - 12\delta_{21}d^2)]}{60m^2t_1N} \quad (851)$$

The simplifications to be effected when $d = m$, *i. e.*, when the load is distributed over the whole span BE are readily found.

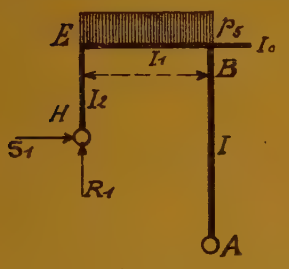


Fig. 12.

If at the same time as $d = m$ we take $p_5 = p_6$, we get for this particular case (see fig. 12) :

$$S = \frac{-p_5m\,(6\delta_1 \quad 4\delta_2m + 3\delta m^2)}{24fhC} \quad (852)$$

$$\mu = \frac{-p_5m\,(6\delta_4 - 4\delta_5m + 3\delta_6m^2)}{72C} \quad (853)$$

$$X = \frac{-p_5m\,(6\delta_7 - 4\delta_8m + 3\delta_9m^2)}{24lN} \quad (854)$$

$$S_1 - S_2 = \frac{p_5m\,(6\delta_{10} + 4\delta_{11}m - 3\delta_{12}m^2)}{12N} \quad (855)$$

$$S_1 + S_2 = \frac{+p_5m\,(6\delta_{13} + 4\delta_{14}m - 3\delta_{15}m^2)}{12hC} \quad (856)$$

$$R_1 + R_2 = \frac{+p_5\,(6\delta_{16} + 4\delta_{17}m - 3\delta_{18}m^2)}{12t_1C} \quad (857)$$

$$R_1 - R_2 = \frac{+p_5\,(6\delta_{19} + 4\delta_{20}m - 3\delta_{21}m^2)}{12t_1N} \quad (858)$$

Seventh case. — Local horizontal load P_6 acting on the pier EH at a vertical distance g from the point E (see fig. 13).

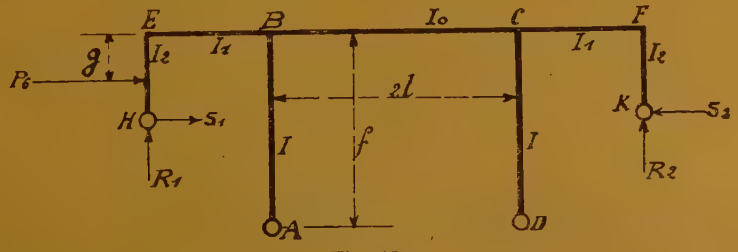


Fig. 13.

If we take :

$$\varepsilon_1 = fhmt_1\,[f^2t\,(4l + mt_1) + l\,(3fmt_1 - 2h^2t_2)] \quad (865)$$

$$\varepsilon_2 = t_2\frac{[2f^2mt_1\,(ft + 3l) + 3fl\,(hmt_1 + 2f^2t\,]}{3} \quad (866)$$

$$\varepsilon_3 = fhmt_1\,[2f^2l - h\,(3mt_1 + 4ht_2)] \quad (867)$$
$$\varepsilon_4 = mt_1\,(2f^3t + 2h^3t_2 + 3fhmt_1) \quad (868)$$
$$\varepsilon_5 = t_2mt_1\,(2f + h) \quad (869)$$
$$\varepsilon_6 = 2f\,[2f^2t\,(l + mt_1) + lmt_1\,(2f + h)] \quad (870)$$
$$\varepsilon_7 = mt_1\,[2l\,(2h + f) + 3hmt_1] \quad (871)$$
$$\varepsilon_8 = 2t_2\,(l + mt_1) \quad (872)$$
$$\varepsilon_9 = hmt_1\,[4ftl + mt_1\,(ft + 3l)] \quad (873)$$
$$\varepsilon_{10} = \frac{2}{3}\,t_2\,[3ftl + mt_1\,(ft + 3l)] \quad (874)$$
$$\varepsilon_{11} = t_2\,[2ftl + mt_1\,(ft + 3l)] \quad (875)$$
$$\varepsilon_{12} = 2fh\,\{f^2t\,(2l + 3mt_1) + l\,[3mt_1\,(f + h) + 2h^2t_2]\} \quad (876)$$
$$\varepsilon_{13} = 2\,[2l\,(f^3t + h^3t_2) + 3mt_1\,(f^3t + h^3t_2 + f^2l + flh)] \quad (877)$$
$$\varepsilon_{14} = t_2\,(2lh - 2fl + 3hmt) \quad (878)$$

we get :

$$S = \frac{P_6\,(f^2h^2C - \varepsilon_1 g - 3\varepsilon_2 hg^2 + \varepsilon_2 g^3)}{2f^2h^2C} \quad (879)$$

$$\mu = \frac{P_6 gt_2 fmt_1\,(2h^2 - 3gh + g^2)}{6hC} \quad (880)$$

$$X = \frac{-P_6\,(\varepsilon_3 - \varepsilon_4 g + 3h\varepsilon_5 g^2 - \varepsilon_5 g^3)}{2lN} \quad (881)$$

$$S_1 - S_2 = \frac{-P_6\,(\varepsilon_6 + \varepsilon_7 g + 3h\varepsilon_8 g^2 - \varepsilon_8 g^3)}{N} \quad (882)$$

$$S_1 + S_2 = \frac{-P_6 g\,(\varepsilon_9 + 3\varepsilon_{10} hg - \varepsilon_{10} g^2)}{h^2C} \quad (883)$$

$$R_1 + R_2 = \frac{+P_6 g\varepsilon_{11}\,(2h - g)\,(h - g)}{mhC} \quad (884)$$

$$R_1 - R_2 = \frac{-P_6\,(\varepsilon_{12} - \varepsilon_{13} g + 3\varepsilon_{14} hg^2 - \varepsilon_{14} g^3)}{mN} \quad (885)$$

These formulæ can be easily checked by making $g = h$ and $g = 0$; when $g = 0$, we find $S = \frac{P_6}{2}$, $\mu = 0$, $S_1 + S_2 = 0$, $R_1 + R_2 = 0$.

Eighth case. — Horizontal load varying from p_7 to p_8, distributed on a length g starting from the point E (see fig. 14).

We find, noting that the values of ε_1 to ε_{14} obtained by formulæ 865 to 878 can still be used :

$$S = \frac{g\,[p_7\,(30f^2h^2C - 10\varepsilon_1 g - 15h\varepsilon_2 g^2 + 3\varepsilon_2 g^3) + p_8\,(30f^2h^2 - 20\varepsilon_1 g - 45h\varepsilon_2 g^2 + 12\varepsilon_2 g^3)}{120f^2h^2C} \quad (886)$$

$$\mu = \frac{g^2 t_2 f l m t_1 \left[(20h^2 - 15hg + 3g^2) + p_8 (40h^2 - 45hg + 12g^2)\right]}{360hC} \quad . \quad . \quad . \quad (887)$$

$$X = \frac{\begin{array}{c} -g\left[p_7 (30\varepsilon_3 - 10\varepsilon_4 g + 15h\varepsilon_5 g^2 - \right. \\ \left. - 3\varepsilon_5 g^3) + p_8 (30\varepsilon_3 - 20\varepsilon_4 g + 45h\varepsilon_5 g^2 - 12\varepsilon_5 g^3)\right] \end{array}}{120lN} \quad . \quad . \quad . \quad . \quad . \quad . \quad (888)$$

$$S_1 - S_2 = \frac{\begin{array}{c} -g\left[p_7 (30\varepsilon_6 + 10\varepsilon_7 g + 15h\varepsilon_8 g^2 - \right. \\ \left. - 3\varepsilon_8 g^3) + p_8 (30\varepsilon_6 + 20\varepsilon_7 g + 45h\varepsilon_8 g^2 - 12\varepsilon_8 g^3)\right] \end{array}}{60N} \quad . \quad . \quad . \quad . \quad . \quad . \quad (889)$$

$$S_1 + S_2 = \frac{-g^2\left[p_7 (10\varepsilon_9 + 15h\varepsilon_{10} g - 3\varepsilon_{10} g^2) + p_8 (20\varepsilon_9 + 45h\varepsilon_{10} g - 12\varepsilon_3 g^2)\right]}{60h^2 C} \quad . \quad (890)$$

$$R_1 + R_2 = \frac{g^2 \varepsilon_{11}\left[p_7 (20h^2 - 15hg + 3g^2) + p_8 (40h^2 - 45hg + 12g^2)\right]}{60mhC} \quad . \quad . \quad . \quad (891)$$

$$R_1 - R_2 = \frac{\begin{array}{c} -g\left[p_7 (30\varepsilon_{12} - 10\varepsilon_{13} g + 15h\varepsilon_{14} g^2 - \right. \\ \left. - 3\varepsilon_{14} g^3) + p_2 (30\varepsilon_{12} - 20\varepsilon_{13} g + 45h\varepsilon_{14} g^2 - 12\varepsilon_{14} g^3)\right] \end{array}}{60mN} \quad . \quad . \quad . \quad . \quad (892)$$

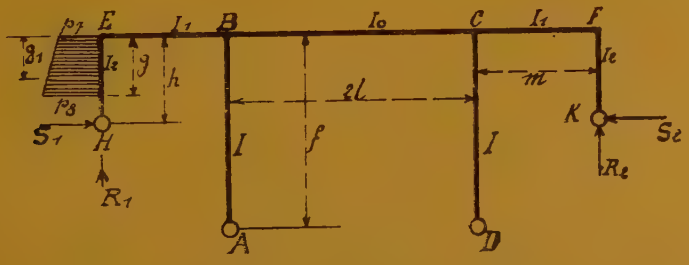


Fig. 14.

The simplifications to be effected when $g = h$, *i. e.* when the load is distributed over the whole height EH can be readily made.

If when making $g = h$, we also take $p_7 = p_8$, we find in this particular case (see fig. 15):

$$S = \frac{p_7 (4l^2 hC - 2\varepsilon_1 - 3\varepsilon_2 h^2)}{8l^2 C} \quad . \quad . \quad . \quad . \quad . \quad . \quad (893)$$

$$\mu = \frac{h^3 t_2 f l m t_1 p_7}{24C} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (894)$$

$$X = \frac{-p_7 h (4\varepsilon_3 - 2\varepsilon_4 h + 3\varepsilon_5 h^3)}{8lN} \quad . \quad . \quad . \quad . \quad . \quad (895)$$

$$S_1 - S_2 = \frac{-p_7 h (4\varepsilon_6 + 2\varepsilon_7 h + 3\varepsilon_8 h^3)}{4N} \quad . \quad . \quad . \quad . \quad . \quad (896)$$

$$S_1 + S_2 = \frac{-p_7 (2\varepsilon_9 + 3\varepsilon_{10} h^2)}{4C} \quad . \quad . \quad . \quad . \quad . \quad . \quad (897)$$

$$R_1 + R_2 = \frac{p_7 \varepsilon_{11} h^3}{4mC} \quad \ldots \ldots \ldots \ldots \quad (898)$$

$$R_1 - R_2 = \frac{-p_7 h (4\varepsilon_{12} - 2\varepsilon_{13} h + 3\varepsilon_{14} h^3)}{4mN} \quad \ldots \ldots \quad (899)$$

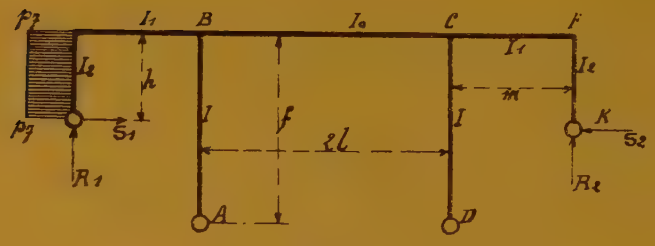


Fig. 15.

NINTH CASE. — Horizontal displacements $\pm \Delta x_A$, $\pm l$ et $\pm l^1$ (positive to the left) at A, H and K respectively (see fig. 16) :

$$S = \frac{\mp EI_0 [\Delta x_A (A - 2B) + 2(e + e') B]}{2f^2 h^2 C} \quad \ldots \ldots \quad (906)$$

$$\mu = \frac{\pm EI_0 m t_1 [h (3mt_1 + 4ht_2) \Delta x_A - 2f^2 l (e - e')]}{2fhC} \quad \ldots \quad (907)$$

$$X = \frac{\pm 3mt_1 (2f + h) EI_0 (\Delta x_A - e - e')}{lN} \quad \ldots \ldots \quad (908)$$

$$S_1 - S_2 = \frac{\pm 12 (l + mt_1) EI_0 (\Delta x_A - e - e')}{N} \quad \ldots \ldots \quad (909)$$

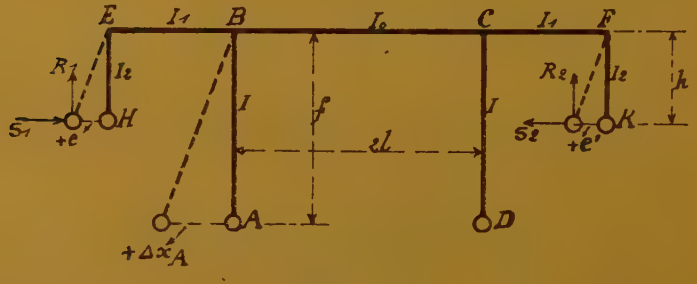


Fig. 16.

$S_1 + S_2$, $R_1 + R_2$, $R_1 - R_2$ are found from (726), (727), (728) using therein the values found in (906), (907), (908) and (909). — The values of A, B, used in (906) and (907) are those of formulæ (714) and (715).

TENTH CASE. Vertical displacements $\pm\Delta y_A$, $\pm d$, $\pm d'$ (positive downwards) at A, H and K respectively (see fig. 17) :

$$S = \frac{\pm 3EI_0 (\Delta y_A - d - d') [f^2 t (2l + mt_1) + 3lmt_1 (f + h) + 2h^2 t_2 l]}{f h m C} \quad . \quad (916)$$

$$\mu = \frac{\pm EI_0 f t (\Delta y_A - d - d') (3mt_1 + 2ht_2)}{mC} \quad . \quad (917)$$

$$X = \frac{\pm 3EI_0 \{(\Delta y_A - d + d') l [2 (f^3 t + h^3 t_2) + 3hmt_1 (f + h)] + 4m\Delta y_A (f^3 t + h^3 t_2 + fhmt_1 + h^2 mt_1 + f^2 mt_1)\}}{l^2 mN} \quad . \quad (918)$$

$$S_1 - S_2 = \frac{\pm 6EI_0 \{l (\Delta y_A - d + d') [hmt_1 + 2l (h - f)] + m^2 t_1 \Delta y_A (2f + h)\}}{mlN} \quad . \quad (919)$$

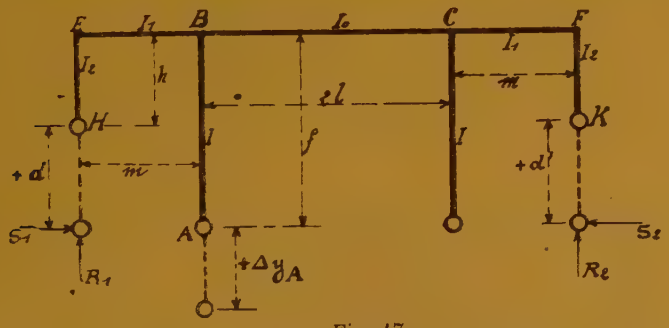


Fig. 17.

$S_1 + S_2$, $R_1 + R_2$, $R_1 - R_2$ are obtained from formulæ (726), (727) and (728) using therein the values found from (916), (917), (918) and (919).

ELEVENTH CASE. — Expansion or contraction $\pm 2\lambda$ of the length BC.

$$S = \frac{\pm EI_0 \lambda A}{f^2 h^2 C} \quad . \quad (926)$$

$$\mu = \frac{\pm EI_0 \lambda m t_1 [2f^2 t - h (3mt_1 + 4ht_2)]}{fhC} \quad . \quad (927)$$

$X = 0$. . . (928) $S_1 - S_2 = 0$. . . (929) $R_1 - R_2 = 0$. . . (930)

$S_1 + S_2$ and $R_1 + R_2$ are given by formulæ (726) and (727) using therein the values found in (926) and (927).

GENERAL NOTES. — I. The whole of the above formulæ can be used no matter what the respective values of f and h may be. However it will be noted that if we make $f = 0$ and $h = 0$, therein respectively S can be found $= \infty$. This result is incorrect because in the equations, the displacement following the x' s of the section at G due to the compression of the section BC has been neglected : this is logical in ordinary cases

wherein f and h have appreciable values. If this displacement be taken into account we shall find when $f = 0$ and $h = 0$ that the value of $S = 0$.

II. If $h = 0$, we get the arrangement shown in sketch A (fig. 18) which differs from the layout B (fig. 19) dealt with in the previous article mentioned at the beginning of

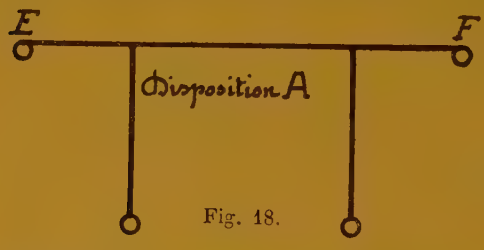


Fig. 18.

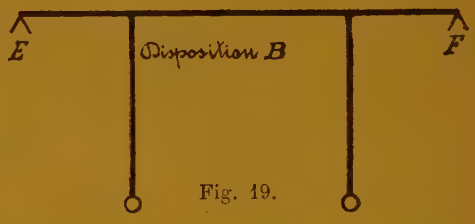


Fig. 19.

this note; in the latter the ends E and F are completely free in the horizontal direction, whereas in sketch A the ends E and F are fixed : the results obtained when $h = 0$ in the present note should not be the same as those found in the sketch B (fig. 19).

III. If the piers EH and FK are brought nearer together horizontally, and the supports AB and CD removed, we again get the case of $f = 0$ and the following layout (fig. 20).

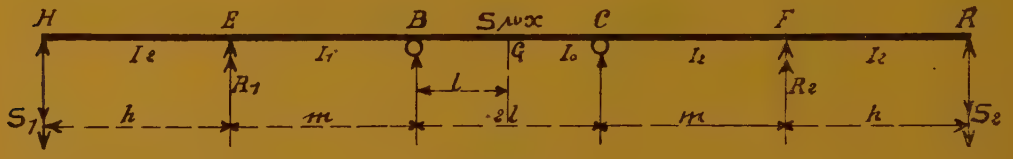


Fig. 20.

In this way we get for the different loadings considered :

First case. — Vertical load P_1 between B and G at a distance a from B (formulæ 740 to 752).

$$S = 0.$$

$$\mu = \frac{P_1 a^2}{4l} \quad \ldots \quad (931)$$

$$X = \frac{P_1 a\,[lmt_1\,(3mt_2 + 4ht_2) + 2a\,(3l - a)\,(ht_2 + mt_1)]}{2l^2\,[mt_1\,(3mt_1 + 4ht_2) + 4l\,(ht_2 + mt_1)]} \quad \ldots \quad (932)$$

$$S_1 + S_2 = 0 \quad \ldots \quad (933)$$

$$S_1 = -S_2 = \frac{-P_1 a\,(l - a)\,(2l - a)\,mt_1}{2lh\,[mt_1\,(3mt_1 + 4ht_2) + 4l\,(ht_2 + mt_1)]} \quad \ldots \quad (934)$$

$$R_1 + R_2 = 0 \quad \ldots \quad (935)$$

$$R_1 = -R_2 = \frac{-P_1 a\,(l - a)\,(2l - a)\,(2ht_2 + 3mt_1)}{2lm\,[mt_2\,(3mt_1 + 4ht_2) + 4l\,(ht_2 + mt_1)]} \quad \ldots \quad (936)$$

Note. — For $a = l$: $S_1 = -S_2 = 0$ and $R_1 = -R_2 = 0$. $X = \frac{P_1}{2}$.

SECOND CASE. — Vertical loads distributed between B and G over a horizontal length a starting from B (formulæ 753 to 760) modified in accordance with the general note I.

$$S = 0. \quad \ldots \quad (937)$$

$$\mu = \frac{(p_1 + 3p_2)a^3}{48l} \quad \ldots \quad (938)$$

$$X = \frac{a^2 \{p_1 [10lmt_1 (3mt_1 + 4ht_2) + 6a (5l - a)(ht_2 + mt_1)] + + p_2 [20lmt_1 (3mt_1 + 4ht_2) + 6a (15l - 4a)(ht_2 + mt_1)]\}}{12l^2 [4l (ht_2 + mt_1) + mt_1 (3mt_1 + 4ht_2)]} \quad \ldots \quad (939)$$

$$S_1 = -S_2 = \frac{-a^2 mt_1 [p_1 (20l^2 - 15al + 3a^2) + p_2 (40l^2 - 45al + 12a^2)]}{60lh [4l (ht_2 + mt_1) + mt_1 (3mt_1 + ht_2)]} \quad \ldots \quad (940)$$

$$R_1 = -R_2 = \frac{a^2 (2ht_2 + 3mt_1) [p_1 (20l^2 - 15al + 3a^2) + p^2 (40l - 45al + 12a^2)]}{120lm [4l (ht_2 + mt_1) + mt_1 (3mt_1 + 4ht_2)]} \quad (941)$$

NOTE. — If $p_1 = p_2$, and $a = l$

$$S = 0 \quad \ldots \quad (942)$$

$$\mu = \frac{p_1 l^2}{12} \quad \ldots \quad (943)$$

$$X = \frac{2p_1 l [mt_1 (3mt_1 + 4ht_2) + 3l (ht_2 + mt_1)]}{4 [mt_1 (3mt_1 + 4ht_2) + 4l (ht_2 + mt_1)]} \quad \ldots \quad (944)$$

$$S_1 = -S_2 = \frac{-p_1 l^3 mt_1}{8h [mt_1 (3mt_1 + 4ht_2) + 4l (ht_2 + mt_1)]} \quad \ldots \quad (945)$$

$$R_1 = -R_2 = \frac{-p_1 l^3 (2ht_2 + 3mt_1)}{8m [mt_1 (3mt_1 + 4ht_2) + 4l (ht_2 + mt_1)]} \quad \ldots \quad (946)$$

For the load covering the whole span BC : $S_1 = -S_2 = 0$; $R_1 = -R_2 = 0$.

THIRD AND FOURTH CASES. — Horizontal load against the upright AB.

These cases need not be considered as we have supposed the upright AB to be removed.

FIFTH CASE. — Vertical load P_5 at a distance d from B on the span BE (formulæ 831 to 844) modified in accordance with the general note I :

$$S = 0. \quad \ldots \quad (947)$$

$$\mu = 0. \quad \ldots \quad (948)$$

$$X = \frac{-P_5 dt_1 [m^2 (3mt_1 + 4ht_2) - 6md (mt_1 + ht_2) + d^2 (3mt_1 + 2ht_2)]}{2lm [mt_1 (3mt_1 + 4ht_2) + 4l (ht_2 + mt_1)]} \quad (949)$$

$$S_1 + S_2 = \frac{P_5 dt_1 [m^2 (2l + 3dt_1) - d^2 (2l + 3mt_1)]}{mh [mt_1 (3mt_1 + 4ht_2) + 4l (ht_2 + mt_1)]} \quad \ldots \quad (950)$$

$$S_1 + S_2 = \frac{3P_5 d^2 t_1^2 (m - d)}{hmt_1 (3mt_1 + 4ht_2)} \quad \ldots \quad (951)$$

$$R_1 + R_2 = \frac{P_5 d^2 t^2_1 [3m(3mt_1 + 2ht_2) - 2d(3m^3 t_1^2 + ht_2)]}{mt^2_1 (3mt_1 + 4ht^2)} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (952)$$

$$R_1 - R_2 = \frac{P_5 dt_1 [2lm(2ht_2 + 3mt_1) + 3dmt_1(2ht_2 + 3mt_1) - 2d^2 t_1 (ht_2 + 3mt_1 + l)]}{m^2 t_1 [4l(ht_2 + mt_1) + mt_1 (3mt_1 + 4ht_2)]} \quad (953)$$

Sixth case. — Vertical load varying between p_5 and p_6 distributed over a length d from B towards E (formulæ 845 to 851 modified in accordance with the general note I).

The results are easily obtained by taking $f = 0$ in formulæ 845 to 851.

In the particular case in which the whole span BE is loaded with the uniformly distributed vertical load p_5, we get :

$$S = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (954)$$

$$\mu = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (955)$$

$$X = \frac{-p_5 m^3 t^2_1 (mt_1 + 2ht_2)}{8l[4l(ht_2 + mt_1) + mt_1 (3mt_1 + 4ht_2)]} \quad . \quad . \quad . \quad . \quad (956)$$

$$S_1 - S_2 = \frac{p_5 m^3 t_1 (2l + mt_1)}{4h[4l(ht_2 + mt_1) + mt_1 (3mt_1 + 4ht_2)]} \quad . \quad . \quad . \quad . \quad (957)$$

$$S_1 + S_2 = \frac{p_5 m^3 t_1}{4h(3mt_1 + 4ht_2)} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (958)$$

$$R_1 - R_2 = \frac{p_5 m[l(4ht_2 + 5mt_1) + 3mt_1 (ht_2 + mt_1)]}{2[4l(ht_2 + mt_1) + mt_1 (3mt_1 + 4ht_2)]} \quad . \quad . \quad . \quad (959)$$

$$R_1 + R_2 = \frac{3p_5 m(mt_1 + ht_2)}{2(3mt_1 + 4ht_2)} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (960)$$

Seventh case. — Local vertical load P_6 acting at a distance g from E on the section EH (formulæ 865 to 885 modified in accordance with the general note I, in which $S = 0$, and $f = 0$).

$$S = 0. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (961)$$

$$\mu = 0. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (962)$$

$$X = \frac{P_6 gt_2 mt_1 (2h - g)(h - g)}{2lh[4l(ht_2 + mt_1) + mt_1 (3mt_1 + 4ht_2)]} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (963)$$

$$S_1 - S_2 = \frac{-P_6 g[hmt_1 (3mt_1 + 4l) - 6ght_2 (mt_1 + l) + 2g^2 t_2 (mt_1 + l)]}{h^2[4l(ht_2 + mt_1) + mt_1 (3mt_1 + 4ht_2)]} \quad (964)$$

$$S_1 + S_2 = \frac{-P_6 g[3hmt_1 + 2gt_2 (3h - g)]}{h^2 (3mt_1 + 4ht_2)} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (965)$$

$$R_1 - R_2 = \frac{P_6 gt_2 (2l + 3mt_1)(2h - g)(h - g)}{mh[4l(ht_2 + mt_1) + mt_1 (3mt_1 + 4ht_2)]} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (966)$$

$$R_1 + R_2 = \frac{3P_6 gt_2 (h - g)(2h - g)}{mh(3mt_1 + 4ht_2)} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (967)$$

EIGHTH CASE. — Vertical load varying from p_7 to p_8 distributed over a length g from E towards H.

Results similar to those in case seven are readily found by making $f = 0$ in formulæ 886 to 892.

For the particular case in which the whole span EH is vertically loaded with an uniformly distributed load of p_7 we get :

$$S = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (968)$$

$$\mu = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (969)$$

$$X = \frac{p_7 h^3 t_2 m t_1}{8l\,[4l\,(ht_2 + mt_1) + mt_1\,(3mt_1 + 4ht_2)]} \quad . \quad . \quad . \quad . \quad (970)$$

$$S_1 - S_2 = \frac{-p_7 h\,[l\,(3ht_2 + 4mt_1) + 3mt_1\,(ht_2 + mt_1)]}{2\,[4l\,(ht_2 + mt_1) + mt_1\,(3mt_1 + 4ht_2)]} \quad . \quad . \quad . \quad (971)$$

$$S_1 + S_2 = \frac{-3p_7 h\,(mt_1 + ht_2)}{2m\,(3mt_1 + 4ht_2)} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (972)$$

$$R_1 - R_2 = \frac{p_7 h^3 t_2\,(2l + 3mt_1)}{4m\,[4l\,(ht_2 + mt_1) + mt_1\,(3mt_1 + 4ht_2)]} \quad . \quad . \quad . \quad (973)$$

$$R_1 + R_2 = \frac{3p_7 h^3 t_2}{4m\,(3mt_1 + 4ht_2)} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (974)$$

NINTH CASE. — Displacements : a) horizontal $\pm\,\Delta\,x_A$ (positively to the left); b) vertical $\pm\,e$ and $\pm\,e'$ (positively upwards at H and downwards at K) at B, H and K respectively.

If f be made $= 0$ in formulæ 906 to 909, and 714 to 716, altered in accordance with the general note I, we get :

$$S = \frac{\mp E\Omega_0 \Delta x_A}{2l} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (975)$$

$$\mu = 0. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (976)$$

$$X = \frac{\pm 3mt_1 EI_0\,(-e - e')}{lh\,[4l\,(ht_2 + mt_1) + mt_1\,(3mt_1 + 4ht_2)]} \quad . \quad . \quad . \quad . \quad . \quad . \quad (977)$$

$$S_1 + S_2 = 0.$$

$$S_1 = -S_2 = \frac{\pm 6\,(l + mt_1)\,EI_0\,(-e - e')}{h^2\,[4l\,(ht_2 + mt_1) + mt_1\,(3mt_1 + 4ht_2)]} \quad . \quad . \quad . \quad . \quad . \quad . \quad (978)$$

$$R_1 + R_2 = 0.$$

$$R_1 = -R_2 = \frac{\pm 3EI_0\,(-e - e')\,(2l + 3mt_1)}{mh\,[4l\,(ht_2 + mt_1) + mt_1\,(3mt_1 + 4ht_2)]} \quad . \quad . \quad . \quad . \quad . \quad . \quad (979)$$

TENTH CASE. — Vertical displacements : $\pm \Delta y_A$, $\pm d$, and $\pm d'$ (positive when downwards) at B, E and F respectively :

By making $f = 0$ in formulæ 916 to 919 altered in accordance with the general note I, and substituting $f^2 t \frac{+ 3lI_0}{fh\Omega_0}(2f + h)$ for $f^2 t$ in formulæ 711 to 718 we get :

$$S = 0 \quad . \quad . \quad .

APPLICATION.

Overbridge to be built for the new railway line from Bruxelles-Midi to Denderleeuw.

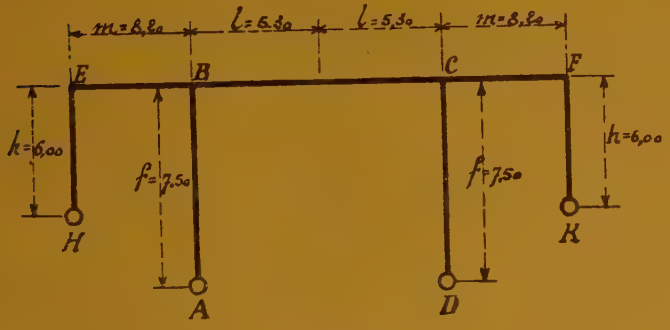


Fig. 21.

$I_0 = 0.04\ m^4.$

$I_1 = 0.03\ m^4.$

$I = 0.004\ m^4.$

$I_2 = 0.004\ m^4.$

$$t = \frac{0.04}{0.004} = 10 \qquad t_1 = \frac{0.04}{0.03} = \frac{4}{3} \qquad t_2 = \frac{0.04}{0.004} = 10.$$

From formulæ (714), (715), (716) and (722) we get :

$$A = 4\,(7.5^3 \times 10 + 6^3 \times 10)\left(3 \times 5.3 + 8.2 \times \frac{4}{3}\right) + 12 \times 5.3 \times 8.2 \times \frac{4}{3}(7.5^2 + 7.5 \times 6 + 6^2) +$$

$$+ \frac{3 \times 6^2 \times 8.2^2 \times 4^2}{3^2} = 4\,(4\,220 + 2\,160)\,26.9 + 696 \times 137 + 108 \times 121 =$$

$$= 686\,488 + 95\,352 + 13\,068 = \mathbf{795\,000.}$$

$$B = 8\,440 \times 26.9 + 22.5 \times 58 \times 21 = 227\,036 + 27\,405 = \mathbf{254\,000.}$$

$$C = 300 \times 5.3 \times 71 + \frac{11}{3}(33 + 240)\,(75 + 15.9) = 112\,890 + 90\,991 = \mathbf{204\,000.}$$

$$N = 4\,(4\,220 + 2\,160)\,(5.3 + 11) + 11\,(21.2 \times 137 + 3 \times 36 \times 11) = 415\,000 +$$
$$+ 45\,000 = \mathbf{460\,000.}$$

1. *Load of 1 000 kgr. per lineal metre over the whole span BC.*

The formulæ to be used are (768) to (774) except that S, μ, $S_1 + S_2$, $R_1 + R_2$ are to be doubled, and X, $S_1 - S_2$ and $R_1 - R_2$ made equal to 0.

$\alpha_1 = 11\,[(33 + 240)\,6 - 2 \times 560] = \mathbf{5\,700.}$

$\alpha_2 = 825\,(80 + 11) = \mathbf{75\,000.}$

$\alpha_3 = 11\,(150 + 16.5 + 120) + 150 \times 60 = 3\,152 + 9\,000 = \mathbf{12\,000.}$

$\alpha_6 = 2\,(4\,220 + 2\,160) + 3 \times 6 \times 11\,(7.5 + 6) = 12\,760 + 2\,670 = \mathbf{15\,430.}$

$$S = \frac{2 \times 1\,000 \times 5.3^3 \times 5\,700}{6 \times 7.5 \times 6 \times 204\,000} = \frac{2 \times 847\,730}{55\,080} = 35 \text{ kgr.}$$

$$\mu = \frac{2 \times 1\,000 \times 5.3^2 (225\,000 + 10.6 \times 12\,000)}{12 \times 204\,000} = 3.45 \times \frac{1\,000 \times 5.3}{12} = 8\,080 \text{ Kg.-M.}$$

$$X = 0. \qquad R_1 = R_2.$$

$$S_1 + S_2 = \frac{-2 \times 2 \times 1\,000 \times 5.3^3 \times 75 \times 11}{3 \times 6 \times 204\,000} = -140 \text{ kgr.}$$

$$S_1 = S_2 = \frac{-140}{2} = -70 \text{ kgr.}$$

$$R_1 + R_2 = \frac{-2 \times 2 \times 1\,000 \times 5.3^3 \times 75\,(33 + 120)}{3 \times 8.2 \times 204\,000} = -1\,370 \text{ kgr.}$$

$$R_1 = R_2 = \frac{-1\,370}{2} = -685 \text{ kgr.}$$

These results make it easy to draw the bending moment diagrams shown below (fig. 22).

$$BO = \frac{5.3^2 \times 1\,000}{2} - 8\,080 = 5\,970 \text{ Kg.-M.}$$

$$NB = BO - BP = 5\,970 - 790 = 5\,180 = -420 + 685 \times 8.2 = 5\,180 \text{ Kg.-M.}$$

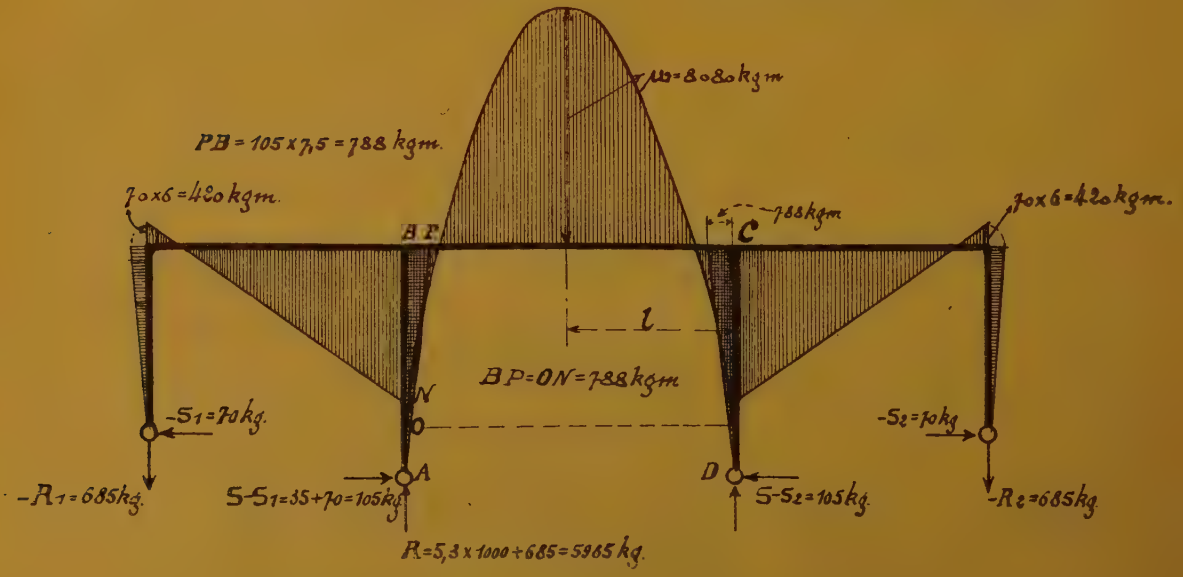


Fig. 22.

NOTE. — If for the same structure we take $t = 2$ instead of 10 we get : $ft = 15$ instead of 75.

$$A = 323\,230 + 95\,352 + 13\,068 = 431\,650.$$
$$B = 45\,407 + 27\,405 = 72\,812.$$
$$C = 22\,578 + 30\,931 = 53\,509.$$
$$\alpha_1 = 11\,[(33 + 240)\,6 - 2 \times 112] = 15\,554.$$
$$\alpha_2 = 15\,000.$$
$$\alpha_3 = 1\,832 + 1\,800 = 3\,632.$$

$$S = \frac{2 \times 1\,000 \times 5.3^3 \times 15\,554}{6 \times 7.50 \times 6 \times 53\,509} = 335 \text{ kgr.}$$

$$\mu = \frac{2 \times 28\,100\,(3 \times 15\,000 + 2 \times 5.3 \times 3\,632)}{12 \times 53\,509} = 7\,314 \text{ Kg.-M.}$$

$$S_1 - S_2 = 0.$$

$$S_1 + S_2 = \frac{-4 \times 149\,000 \times 15 \times 11}{3 \times 6 \times 53\,509} = -102 \text{ kgr.}$$

whence

$$S_1 = S_2 = -51 \text{ kgr.}$$
$$R_1 - R_2 = 0$$

$$R_1 + R_2 = \frac{-4 \times 149\,000 \times 15\,(33 + 120)}{3 \times 8\,2 \times 53\,509} = -1\,040 \text{ kgr.}$$

whence

$$R_1 = R_2 = -520 \text{ kgr.}$$

When these results are considered in conjunction with those above the important effect on the exact determination of the stresses of the values of I at the different points of the structure being examined will be seen.

2. *Load of 1 000 kgr. per lineal metre on each of the sections EB and CF.*

The formulæ to be used are 852 to 858 except that owing to the symmetrical arrangement the values of S_1, μ_1. $S_1 + S_2$ and $R_1 + R_2$ are to be doubled, and X_1, $S_1 - S_2$ and $R_1 - R_2$ cancelled out.

$$\delta_1 = 5.3 \times 8.2 \times 11\,[6\,(33 + 240) - 2 \times 560] = 247\,700.$$
$$\delta_2 = 11\,[7.5 \times 11 \times 90.9 + 5.3 \times 36 \times 71] = 231\,500.$$
$$\delta_3 = \frac{4}{3}\,[7.5 \times 11 \times 90.9 + 5.3 \times 6\,(33 + 120) + 10.6 \times 560] = \frac{4}{3} \times 18\,350 = 24\,400.$$
$$\delta_4 = 7.5 \times 11 \times 8.2 \times 273 = 1\,846\,800.$$
$$\delta_5 = 6 \times 75 \times 11 \times 71 = 351\,450.$$
$$\delta_6 = \frac{75 \times 4}{3} \times 153 = 15\,300.$$
$$\delta_{13} = 2 \times 75 \times 5.3 \times 11 \times 8.20 = 71\,700.$$
$$\delta_{14} = 121 \times 90.9 = 11\,000.$$
$$\delta_{15} = \frac{4}{3}\,[11 \times 90.9 + 10\,6 \times 75] = 2\,400.$$

$$\delta_{16} = 2 \times 75 \times 5.3 \times 11 \times 153 = 1\,338\,000.$$

$$\delta_{17} = \frac{4}{3} \times 11 \times 153 \times 90.9 = 204\,000.$$

$$\delta_{18} = \frac{32}{9}[75(11 + 5.3 + 20) + 5.3 \times 93] = \frac{32}{9} \times 3\,215 = 11\,400.$$

$$S = \frac{-2 \times 8\,200(6 \times 247\,700 - 32.8 \times 231\,500 + 3 \times 24\,400 \times 8.2^2)}{24 \times 45 \times 204\,000} =$$

$$= \frac{-(1\,486\,200 - 7\,593\,200 + 4\,921\,500)\,16\,400}{1\,080 \times 204\,000} = +72 \text{ kgr.}$$

$$\mu = \frac{-2 \times 8\,200(6 \times 1\,846\,800 - 32.8 \times 351\,450 + 3 \times 8.2^2 \times 15\,300)}{72 \times 204\,000} = -2\,950 \text{ Kg.-M.}$$

$$X = 0. \qquad S_1 - S_2 = 0. \qquad R_1 - R_2 = 0.$$

$$S_1 + S_2 = \frac{+2 \times 8\,200(6 \times 71\,700 + 32.8 \times 11\,000 - 3 \times 8.2^2 \times 2\,400)}{12 \times 6 \times 204\,000} = 344 \text{ kgr.}$$

$$S_1 = S_2 = \frac{344}{2} = 172 \text{ kgr.}$$

$$R_1 + R_2 = \frac{2 \times 1\,000(6 \times 1\,338\,000 + 32.8 \times 204\,000 - 3 \times 8.2^2 \times 11\,400)}{12 \times 204\,000 \times \frac{4}{3}} = 7\,570 \text{ kgr.}$$

$$R_1 = R_2 = \frac{7\,570}{2} = 3\,785 \text{ kgr.}$$

From these figures the bending moment diagram given below (fig. 23) can be readily drawn.

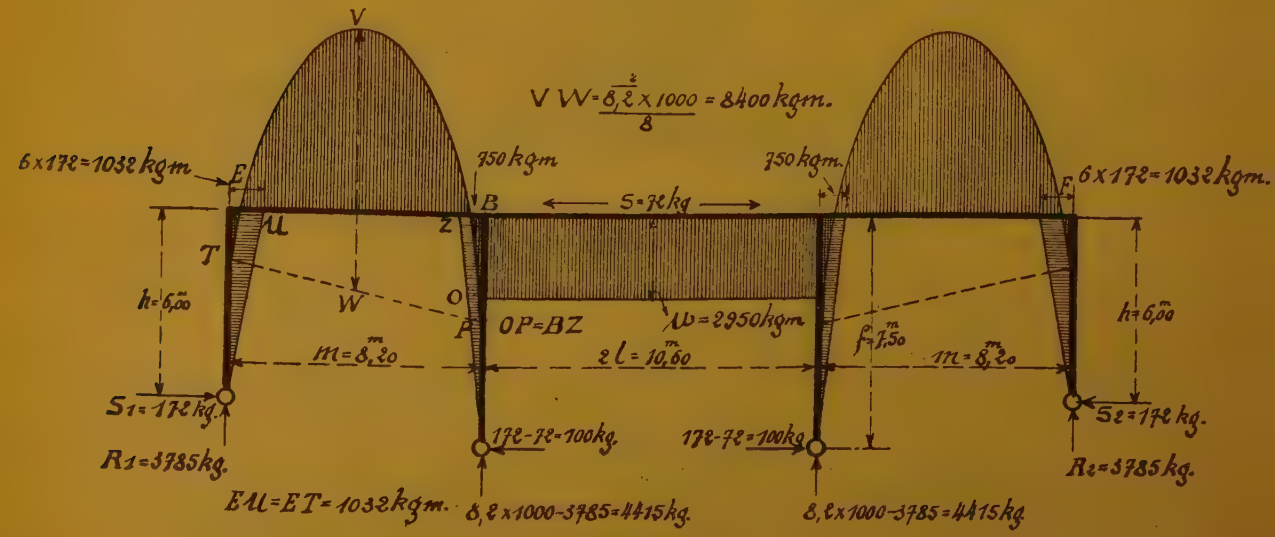


Fig. 23.

NOTE. — Taking $t_2 = 2$ instead of 10 as before we get by formula (716) in particular.

$$C = 300 \times 5.3\,(11 + 12) + \frac{11}{3}\,(33 + 48)\,(75 + 15.9) = 36\,570 + 27\,000 = 63\,570$$

instead of 204 000; as δ_{13}, δ_{14}, δ_{15} do not alter we get

$$S_1 = S_2 = \frac{172 \times 20\,400}{63\,570} = 550 \text{ kgr.}$$

instead of 172 and at B and F moments of 3 300 Kg.-M. instead of 1 042.

This example again shows the importance of the values of I at the different points of the structure on the exact determination of the stresses.

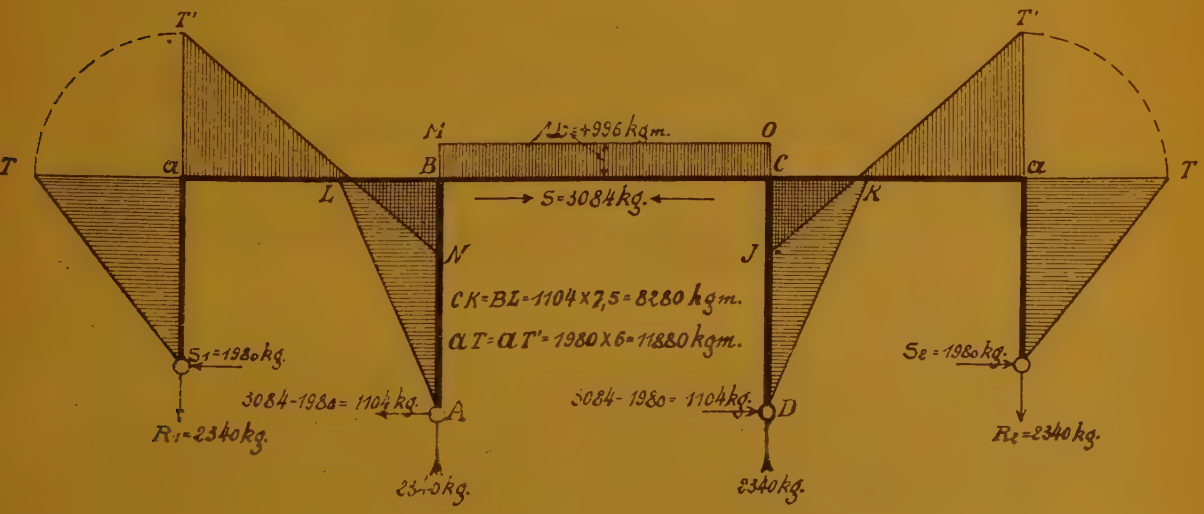


Fig. 24.

3. *Contraction — 2λ = 0.04 m. resulting in the section BC from a fall of temperature or a contraction of the concrete.*

Formulæ to be used : 920 to 930. Taking E = 2 000 000 000 for concrete I_0 of 0.04 value

$$S = \frac{-2 \times 10^{9} \times 0.04 \times 0.02 \times 795\,000}{7.5^{2} \times 6^{2} \times 204\,000} = -3\,084 \text{ kgr.}$$

$$u = \frac{-2 \times 10^{9} \times 0.02 \times 0.04\,(2 \times 560 - 6 \times 273)\,11}{7.5 \times 6 \times 204\,000} = 996 \text{ Kg.-M.}$$

$$X = 0; \qquad S_1 = S_2; \qquad R_1 = R_2;$$

$$S_1 + S_2 = \frac{-4 \times 7.50 \times 11 \times 3\,084 + 4 \times 996 (15.9 + 11)}{11 \times 21} = -3\,960 \text{ kgr.}$$

$$S_1 = S_2 = -1\,980 \text{ kgr.}$$

$$R_1 + R_2 = \frac{-5.3 \times 2 \times 996 - 18 \times 11 \times 3\,960}{2 \times 11 \times 8.2} = -4\,680 \text{ kgr.}$$

$$R_1 = R_2 = -2\,340 \text{ kgr.}$$

These values are used to draw the bending moment diagram above (fig. 24).

Note. — If in the same structure we take $t = 2$ instead of $t = 10$ we get $ft = 15$ instead of 75; this gives A = 431 650, C = 53 509 as calculated previously.

$$S = \frac{-2 \times 10^{9} \times 0.04 \times 0.02 \times 431\,650}{7.5^{2} \times 6^{2} \times 53\,509} = -6\,384 \text{ kgr.}$$

$$\mu = \frac{-2 \times 10^{9} \times 0\,04 \times 0.02\,(2 \times 7.5 \times 15 - 6 \times 273)\,11}{7.5 \times 6 \times 53\,509} = -10\,332 \text{ Kg.-M.}$$

This shows once again the importance of the values of I on the exact determination of the stresses in the different parts of the structure.

625 .143.3]

Breaking of rails in service due to transverse fissures (silvery oval mark).

Figs. 1 to 9, pp. 679 to 685.

As a supplement to the article under this title published in the August 1926 number of the English Edition of our *Bulletin*, page 696, we print below extracts from the recent reports drawn up by the Rail Committee of the American Railway Engineering Association and of the American Railway Association, from the statistics of rail breakages which had been sent to it. This information has been forwarded to us by the American Railway Association and describes the practice of the American railways in this matter.

Extract from the report of the Rail Committee of the American Railway Engineering Association.

The Engineer of Tests of the Delaware, Lackawanna & Western Railroad in his private capacity as Consulting Engineer, further replied to Mr. Borland's published letter, his comment being published in the *Railway Age*, issue of 20 February 1926 :

Rails, fissures and « voids » (1).

I cannot refrain from comment on the editorial concerning transverse fissured rails in your issue of 5 December, and the remarkable letter from Director Borland of the Bureau of Safety in the issue of 26 December.

The quality of steel rail in resistance to failure has for many years occupied, and will continue to engross most of my personal attention. As one of the metallurgists primarily in railway service, I think that both mill and track must join in pleading guilty to your indictment of not having settled the transverse fissure problem, and throw ourselves on the mercy of the court of engineering opinion. We should, however, be granted a suspended sentence, provided speedy productive scientific activity characterizes our course.

If steel rail as a class is really being overworked, Mr. Borland's pessimistic state of mind would seem justified, and all those responsible for its metallurgical condition would share in his distress, especially as the harder and stronger rails, not only according to chemical composition, but also in physical compactness and homogeneity of structure, appear to display in a small percentage of their total production lessened resistance to storing up cooling and cold rolling strains. We must admit that it is hardly now possible to make rail as a class more resistant to these cumulative

(1) The last word alludes to Mr. Borland's phrase : « The space between the walls of a transverse fissure is a void ». (*Editor's note.*)

strains without encountering worse difficulties in many other directions. The issue, therefore, is whether or not rail in general is being overworked.

I happen to be familiar with the rather complete track record of nearly 16 000 rails broken from simple transverse fissure over the last twelve years, and reasonably familiar with the manufacturing data on a considerable portion of them. Without intending to primarily discuss these data, as they will be submitted within a short time to an official co-operative investigating body, Mr. Borland's estimates in his letter are in general correct. Of the 50 000 000 rails whose useful life would have otherwise been unattended by serious disaster, 16 000 failed through this particular defect. Without endeavoring to mitigate the seriousness of our present situation, perhaps less than 100 of these breaks have been attended by any injury to life or limb, and relatively few of the remainder by derailments causing property damage. One cannot admit Mr. Borland's view that a proportionate number of the rails now in track may be expected to fail with equal menace, as the data indicate a considerable reduction of the failure rate in the East since certain rollings from certain mills, rolled from ten to fifteen years ago, have been worked out of track. Doubtless there will be, in the West, an increasing number of fissure failures for a few years to come. This is due to their now reaching only the equivalent amount of service, from rollings in these same periods, as was accumulated on the eastern roads in a much shorter time. The relative traffic densities entirely account for the situation, inasmuch as no one can quarrel with Mr. Borland's diction in stating that the *development* of transverse fissures is quite entirely a function of the number and loaded weight of wheels passing over rails which have the nucleus of failure. Metallurgists of the railways believe the nucleus in rails to be pre-existent to track service, and that without its presence our heaviest loads and traffic densities have never, to our knowledge, developed a detail transverse fatigue failure whose origin is in the zone stressed both by cooling and service. One of the surest indications that the weight of the load itself or the speed has but little to do with it, is that western conditions of lighter loads and relatively lower speeds are developing transverse fissure failures from the same old kind of nuclei, but are taking over twice the number of repetitions of lighter loaded wheels to develop them to ultimate failure.

Mr. Borland states that all of the 50 000 000 or more rails in service were subjected to cooling strains in no respect different from the few which have displayed transverse fissures. It would seem that he rather curiously mistakes cause for effect. One might agree that the stresses set up in the more or less yielding hot metal through cooling are in general of the same order of magnitude for any one section, but the strains remaining in the rail head after leaving the hot beds are not only functions of the stresses, but are more specifically functions of the ability of the particular heat in plastic yielding. That differences exist from heat to heat in this respect is unquestionable, whether the metal goes in to rails or side frames, and those differences are independent of the rate of cooling, except that the more rapid the cooling the more apt cracks are to develop. If cooling is gentle, the strains persist without the crack.

These variations in hot ductility, plasticity, or whatever one may choose to call it, may or may not be intimately related with gas inclusion, but many investigative laboratories, in working on such defects as snowflakes in gun and other alloy steels, have very clearly proven the variations quantitively as of considerable magnitude.

While Mr. Borland states that the nu-

cleus is « nothing », therefore a void, this line of reasoning should therefore be extended to calling a crack a void, and therefore nothing. If a crack is a result of a manufacturing condition, Mr. Borland believes that, being nothing, it should not be called a defect. He defines a defect as something which must be known as a definite entity. This seems to be a quibble when applied to a shrinkage crack, concerning which a distinguished engineer-physicist has stated, « Any one of which would seem might be the starting point of a transverse fissure, among those properly oriented ».

An extremely important justification for hope lies in the efforts of a distinguished scientist who has gone far in developing a track recording device by which growing transverse fissure discontinuities within the rail head may be detected. Unfortunately neither it nor any device known to science in its present state can hope to reveal the presence of such small discontinuities as the nucleus or shattering crack during inspection either by the mill's own organization or those serving the railways in this capacity.

Some of us have pretty well defined leads as to their probable cause. An investigation is now proceeding, sponsored, at railway initiative, by the Department of Commerce. Facts, not theories, as to the history in mill and track of all known transverse fissured rails and heats, will point the way toward utilizing the facilities of the laboratory of the Bureau of Standards, as well as the laboratories of both railways and rail mills. This will go far, in my judgment, toward permanently settling the issue and providing adequate remedy.

JOHN B. EMERSON,
Vice-President,
R. H. Laverie & Sons, Inc.

At a special meeting of the Rail Committee, held on 26 January 1926, the members of the Committee unanimously instructed the Chairman to make the following statement :

Statement by Rail Committee

Under date of 19 December 1925, Director Borland of the Bureau of Safety of the Interstate Commerce Commission addressed a letter and questionnaire to numerous railway engineers requesting co-operation in furnishing both facts and opinions pertinent to investigation of the cause of transverse fissures in steel rails.

At a meeting of the Board of Direction of the Association, held soon after the issuance of this letter, the importance of fundamental data in serving as a basis of reply was fully realized.

President Fairbairn, under date of 15 January, issued a circular letter stating that the Rail Committee would furnish all data available upon request. The enclosed memorandum covers in a general way the complete track history and all mill information available concerning some 16 000 rails failing from simple transverse fissure, up to and including the year 1923. Charts and tables are presented classifying and correlating these fissures according to the mills in which the rails were made, the years in which they were rolled, the heats of which the rails were part and the dates of failure in tracks of specific railways.

Certain conclusions based on study of these data have been reached by the Rail Committee, among which perhaps the most decisive is that certain rollings from certain mills display remarkable proneness to failures of this type; that certain of the mills whose output goes into service under heavy traffic display through their entire life production comparatively few failures, while other mills display over their entire production great quantities of fissures; further that of the mills whose isolated rollings show large fissure production, most rollings show only an average rate.

The Rail Committee further believes that while the number of transverse fissure failures reported has been increasing during the last few years, the metal rolled since about 1912 has been in general steadily improving in resistance. It attributes the increase by years entirely to the presence in track, under restricted traffic, of the early rollings whose fissure development proceeded to rupture some years ago under heavy traffic. The Committee has charted the decreasing trend of fissure production, which is a very important exhibit in these data.

The Rail Committee has reason to believe that the shattering crack is the nucleus of the transverse fissure, and that without its pre-existence no detail transverse fatigue failure has ever been developed from the interior zone in the rail head admittedly stressed by service conditions. It is recognized that the growth or development of a transverse fissure from a shattering crack or nucleus must await the impingement of the rolling load, and that the less the area of contact, the heavier the load, and the greater the number of repetitions, the more rapidly the fissure will grow. These data show, however, that relatively light traffic also develops fissures from shattering cracks, except that the growth is slower.

The Rail Committee has reason to believe that the real crux of this problem does not lie in the impinging pressure of the wheel upon the head of the rail, but rather lies in determining the cause of the shattering crack at the steel mill. When the cause is determined, its elimination may be reasonably expected.

Mr. Elmer Sperry, of the Sperry Gyroscope Company, Brooklyn, New York, was a guest at the Rail Committee meeting, and extended to the railways in general an opportunity to co-operate in the final development of his transverse fissure detector, a clever electrical apparatus operating through bi-polar brushes contacting through slide on the rail head and sending a heavy amperage of direct current through the rail between the brushes. Through an entirely separate circuit, also brush contacting between the heavy current contacts, minute variations in potential caused by growing cross-sectional discontinuity are registered and tremendously amplified through the use of well-known radio principles. Tests made in Mr. Sperry's laboratory indicate that a transverse fissure growing to an extent of 15 % of the cross-sectional area of the head may be registered and synchronized on a recording tape, the magnitude of deflection on the tape for this amount of discontinuity being not far from an inch.

Professor A. N. Talbot, of the University of Illinois, Chairman of the Committee on stresses in railroad track, further advised the Rail Committee that tests in progress for over a year at the University revealed striking dissimilarity in elastic constants between representative specimens of rail steel from heats prone to transverse fissure, as contrasted with heats of the same chemistry and life in service. These differences are technically expressed as variations in Poisson's ratio, the fissured heats showing an index figure of 0.27, while for the non-fissured heats an index number of 0.23 was registered, with relatively little variation from the average in each case.

The Rail Committee further calls to your especial attention the general bibliography and discussion of transverse fissures published in the 1923 Proceedings of the American Railway Engineering Association as Appendix D of the Rail failure report, Volume 22, page 655. The various studies leading to the identification of the transverse fissure nucleus with the shattering crack are listed therein, culminating in the work of Waring, Hofammann, and Rawdon.

Bulletin No. 283 of the American Railway Engineering Association, just off the press, contains the Rail Committee's formal report to the convention, and your

attention is also invited to Appendix E of the report, entitled « Study of the effect of various intensities and repetitions of wheel loads upon rails ». This Bulletin should be in your hands before this report reaches you.

Transverse fissure statistics,

By JOHN B. EMERSON,
ENGINEER OF TESTS, RAIL COMMITTEE.

February 1926.

This compilation includes approximately 15 300 transverse fissures known to be of the simple, or vertical transverse type, unaccompanied by head splits in other planes. It has become generally recognized that compound or coalescent detail fatigue failures arise largely from a segregated condition in the interior of the rail head, and that the vertical transverse component is incidental.

Table No. 1 exhibits the reporting railways with the number of failures in track by years failed from 1910 to 1923 inclusive. The track mileage represented embraces over one-half the total of American railway systems.

Table No. 2 classifies all the fissure failures accumulated from year rolled to 1923 inclusive for each year's rolling for each mill, running as far back as the rollings of 1889. The total accumulation for each year's rolling from all mills indicates the increasing tendency toward fissures, reaching its present maximum in the rollings of 1910. It is noteworthy that this rolling has been in track over fifteen years. The totals for the individual mills for the entire period indicate in general their comparative tendencies toward transverse fissure, without weighting by the tonnage outputs of the mills, or the relative severity of service endured.

Table No. 3 classifies fissure failures whose mill analyses are available by carbon content, together with an estimate of the percentage of high and low carbon heats present in track and a rating on this basis.

Table No. 4 follows on from the data in table No. 2 by rating the mills comparatively in proportion to the number of fissures per 10 000 tons of rail produced for reporting roads.

Table No. 5 exhibits the heats in which fissures have occurred, classified by mills and multiple failures from date rolled to 1923 inclusive. In the column « All mills » is shown the number of heats developing a given number of fissures, while under the last column « Cumulative » the numbers represent totals of two or more, three or more, etc.

It is interesting to note that the number of heats showing more than one fissure is approximately 1 800 as against about 7 200 heats showing one fissure. This shows the chance of a heat developing more than one after having suffered its first to actually be 1 to 4. It further shows a total of about 900 with three or more. The number showing two being about 900, the chance of its picking up a third after it has suffered two is even money. The table shows a little over 500 heats with four or more and about 350 heats with three only, the chance therefore of its picking up more after having suffered three rising to 1 1/2 to 1. Without going down these columns in detail, the number of heats with nine or more is 66, while the number with eight is 23, or odds in favor of additional fissure being about 3 to 1. Following the column down into the extreme number of multiple fissure failures is not

TABLE No. 1.

Simple transverse fissure failures by railroads and by year failed.

RAILROAD.	1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923	Total.
Atchison, Topeka & Santa Fe	...	...	...	1	...	1	6	19	13	25	177	220	134	126	722
Boston & Albany	...	...	...	...	...	2	1	...	1	17	23	30	25	15	114
Boston & Maine	...	...	...	...	...	...	...	...	...	...	...	...	...	35	35
Baltimore & Ohio	...	...	...	...	...	...	...	...	...	...	...	...	...	212	212
Buffalo, Rochester & Pittsburgh	...	...	...	...	...	...	...	...	...	...	...	...	9	11	20
Chesapeake & Ohio	...	...	...	...	...	...	...	...	...	...	...	6	26	46	78
Central of Georgia	...	...	...	...	...	...	3	51	52	52	23	41	31	29	282
Cleveland, Cincinnati, Chicago & St. Louis	...	...	...	...	...	...	...	...	...	...	...	...	2	1	3
Chicago, Rock Island & Pacific	...	...	...	...	...	1	2	6	1	2	11	25	37	75	160
Chicago, Milwaukee & St. Paul	...	...	...	...	...	...	...	...	2	...	6	5	14	11	38
Canadian Pacific	...	...	...	...	...	...	...	...	...	4	...	8	16	59	87
Chicago, Burlington & Quincy	...	...	...	...	...	...	...	...	...	1	7	34	101	87	230
Delaware, Lackawanna & Western	...	...	17	20	20	32	76	112	197	193	240	169	91	80	1 247
Erie	...	...	...	...	...	...	...	...	...	...	...	...	15	43	58
El Paso & South Western	...	...	...	...	...	...	...	...	...	...	...	...	8	6	14
Hocking Valley	...	...	...	...	...	...	...	...	...	...	...	...	13	53	66
Illinois Central	...	1	1	...	...	...	2	3	4	35	121	190	372	556	1 285

Louisville & Nashville .	...	...	...	Prior to 1919.			...	...	474	9	17	33	43	77	653
Lehigh Valley	...	...	...	...	...	...	...	...	...	...	...	...	57	89	146
Lehigh & New England	...	...	...	...	...	...	...	...	...	...	...	...	...	32	32
Lehigh & Hudson . . .	...	...	...	...	...	...	...	...	...	...	...	1	...	4	5
Long Island.	...	...	...	...	...	...	...	...	...	...	...	2	8	7	17
Michigan Central. . . .	...	...	...	...	...	...	...	...	...	...	...	...	...	2	2
Missouri Pacific	...	...	...	...	...	...	...	...	...	...	...	...	2	8	10
Missouri, Kansas & Texas.	...	...	...	...	...	...	...	...	...	...	...	2	11	13	26
Nashville, Chattanooga & St. Louis.	...	...	...	...	2	3	1	4	...	...	1	2	2	8	23
Norfolk & Western. . .	...	...	...	...	...	...	...	...	...	...	...	...	3	17	20
New York, Chicago & St. Louis.	...	...	...	...	...	...	...	...	...	...	...	...	...	2	2
New York, New Haven & Hartford.	...	...	...	...	...	...	...	...	...	...	...	...	12	28	40
New York Central (East)	...	...	...	4	43	76	124	101	67	84	88	93	136	107	923
New York Central (West)	...	...	...	...	...	...	...	...	...	...	1	18	37	16	72
Northern Pacific	...	...	...	...	...	...	...	...	...	...	...	...	42	39	81
Pennsylvania	...	...	...	...	65	370	532	550	727	1 114	1 129	1 104	904	649	7 144
Reading.	...	...	...	...	...	...	...	...	...	...	...	...	52	112	164
Southern Pacific	...	...	15	4	6	11	15	4	2	9	6	130	118	143	463
Southern Railway . . .	...	...	...	...	...	...	...	...	...	...	...	...	...	24	24
Union Pacific.	...	...	...	...	...	...	...	...	...	...	...	36	262	557	855
All roads. . .	...	1	33	29	136	496	762	850	1 540	1 545	1 850	2 149	2 584	3 382	15 357

Table No. 2.

Accumulated simple transverse fissure failures from year rolled to 1923, inclusive, by years rolled and by mills.

YEAR.	Unknown.	Lorain.	German.	Inland.	Bethlehem.	Tennessee.	Pennsylvania.	Maryland.	Lackawanna.	Cambria.	Illinois.	Colorado.	Dominion.	Algoma.	Carnegie.	All mills.
Unknown . . .	1	...	...	...	4	1	1	...	9	1	86	13	2	7	8	133
1889.	...	...	...	...	...	...	2	...	...	...	...	...	...	...	...	2
1890.	...	...	...	...	...	...	5	...	1	...	...	...	...	...	...	6
1891.	...	...	...	...	...	...	3	...	4	...	...	...	...	...	1	8
1892.	...	...	...	...	...	...	2	1	...	2	...	...	...	...	...	5
1893.	...	...	...	...	...	...	...	2	...	1	...	...	...	...	...	3
1894.	...	...	...	...	...	...	3	1	...	5	...	...	...	...	...	9
1895.	...	...	...	...	...	...	1	...	1	5	...	...	...	...	1	8
1896.	...	...	...	...	...	...	3	...	4	...	1	...	...	...	...	8
1897.	...	...	...	...	...	...	7	...	8	10	...	...	...	...	5	30
1898.	...	...	...	...	...	...	7	1	19	13	...	...	...	...	2	42
1899.	...	...	...	...	...	...	18	3	11	14	...	...	...	...	4	50
1900.	...	...	...	...	...	...	11	5	...	15	...	...	...	...	4	35
1901.	...	...	...	...	...	...	...	9	18	25	2	...	...	...	15	69
1902.	...	...	2	...	2	...	...	30	2	57	1	...	...	...	31	125
1903.	...	...	...	...	...	25	...	42	...	51	4	...	...	...	30	478

1904.	...	...	...	...	...	189	...	12	4	21	...	1	...	...	...	...
1905.	...	...	2	...	...	318	5	19	7	20	5	...	...	...	29	405
1906.	...	3	...	...	1	45	1	41	1	48	1	...	3	...	29	173
1907.	...	...	...	...	10	60	...	65	13	63	16	2	...	1	18	248
1908.	...	...	...	...	183	27	...	1	4	11	...	...	10	...	...	236
1909.	...	...	...	...	982	5	82	40	50	70	212	3	...	1	7	1 452
1910.	2	...	...	...	393	59	90	78	84	95	1 004	111	...	2	2	1 920
1911.	...	...	...	...	504	92	88	171	266	312	118	76	...	2	33	1 662
1912.	1	...	...	...	79	60	16	102	669	306	383	22	12	1	15	1 666
1913.	2	1	...	...	103	42	49	277	525	334	378	3	...	3	12	1 729
1914.	...	...	...	...	91	78	86	96	450	201	77	15	...	2	16	1 112
1915.	1	...	...	...	165	18	84	298	135	81	136	84	...	108	8	1 118
1916.	...	...	...	...	194	60	8	142	38	35	130	50	...	39	23	719
1917.	1	...	...	...	76	53	...	283	33	80	373	26	...	2	16	943
1918.	...	...	...	..	14	69	7	27	44	37	85	7	12	30	12	344
1919.	...	...	...	...	71	22	23	7	9	1	138	1	2	28	3	305
1920.	...	...	...	...	6	19	23	...	3	26	52	8	...	13	15	165
1921.	...	...	...	...	15	7	9	...	12	19	15	6	...	...	10	93
1922.	...	...	...	10	1	32	3	1	5	5	3	1	...	...	8	69
1923.	...	...	...	...	1	9	10	...	7	1	...	...	...	...	...	28
Total. . .	8	4	4	10	2 895	1 290	647	1 754	2 436	1 965	3 217	429	41	239	418	15 357

TABLE No. 3.

Interior fissure failures classified by carbon content.

Per cent.	Number of failures.	Per cent.	Number of failures.
0.58	8	Carried over. . .	2 639
0.59	5	0.75	238
0.60	21	0.76	101
0.61	20	0.77	64
0.62	83	0.78	53
0.63	113	0.79	62
0.64	135	0.80	37
0.65	156	0.81	27
0.66	176	0.82	28
0.67	211	0.83	13
0.68	245	0.84	11
0.69	253	0.85	7
0.70	248	0.86	9
0.71	257	0.87	5
0.72	278	0.88	1
0.73	197	0.89	1
0.74	233	0.90	2
To be carried over .	2 639	Total. . .	3 298

Carbon 0.58 to 0.70 inclusive : 1 674 interior fissure failures.
— 0.71 to 0.90 — 1 624 — — —

Illinois Central tabulation of 6 000 heats from Gary, Tennessee and Algoma. Classified by number of heats of given carbon content.

	Illinois.	Tennessee.	Algoma.	Total.
Carbon below 0.71	69	78	76	223
Carbon 0.71 and over	31	22	24	77

Ratio production low carbon heats to high carbon : 3 to 1.
Applying this ratio to general tabulation :

$1\,674 \times 1/3 = 558$ | $1\,624 \times 2/3 = 1\,082.$

Rate of failure, high carbon heats to low carbon heats : 1.9 to 1.

TABLE No. 4

Rate of accumulated transverse fissure failures from year rolled to 1923, inclusive, by mills and years rolled.

Basis of rating is number of fissures per 10 000 tons of rail produced for reporting roads.

YEAR ROLLED.	Pennsylvania.	Carnegie.	Cambria.	Illinois.	Colorado.	Tennessee.	Lackawanna.	Maryland.	Bethlehem.	All mills.
1909	23.2	1.0	21.6	9.4	1.2	0.9	12.6	10.2	275.1	25.8
1910	16.6	0.3	22.3	32.6	19.0	13.3	8.1	14.1	97.1	24.6
1911	21.7	5.0	60.2	7.5	14.4	15.1	71.7	31.9	81.3	28.6
1912	3.7	2.6	48.1	15.4	3.9	8.4	102.2	49.8	13.7	23.4
1913	4.4	0.8	34.5	18.1	0.4	4.5	63.3	33.3	10.6	17.5
1914	14.5	2.3	30.7	6.8	2.1	12.7	110.3	33.1	14.5	19.5
1915	17.2	0.5	13.7	6.5	8.5	4.5	23.1	81.7	34.2	13.5
1916	10.0	2.0	2.5	5.2	7.2	16.8	5.3	16.8	31.3	8.2
1917	...	1.6	13.0	16.4	3.1	5.8	4.7	73.8	1.0	12.6
1918	10.3	1.2	12.2	3.1	1.3	9.9	4.2	9.6	2.3	4.1
1919	14.8	0.4	3.5	6.4	0.1	2.5	1.2	2.5	7.1	4.0
1920	5.4	1.2	9.6	1.7	0.9	1.8	0.2	0.0	1.4	1.6
Average.	11.9	1.4	23.5	11.2	4.9	7.1	24.7	30.5	35.8	14.5

productive, as of course very few heats remain in track after showing nine fissures.

Estimates on the number of rails and heats in track made by the Committee, which checks pretty closely with the estimate made in Mr. Borland's letter, indicates that only about one heat in 50 ever shows a fissure during its useful life and therefore that the next fissure should, if there is no difference in the character of the heats, fall in a heat other than one in which the first failure occurred. According to this, and applying the laws of probability as checked by competent mathematicians, the chance of any given heat developing two fissures would be not far from 1 to 2 000, while applying the actual data, the chance of a heat developing two fissures appears to be about 1 to 500. The chance of a heat developing three fissures, if all heats were similar in character, in theoretical probability would be about 1 to 200 000, whereas by the data the chance appears to actually be about 1 to 1 200. The chance of any given heat having four or more failures would continue, according to the law of probability, to lessen ad infinitum.

Table No. 6 contains fundamental data concerning the relation between traffic density and fissure development, the traffic density being assumed for this purpose as ton miles per year per mile of track. The entire output for reporting roads from three mills is classified by railway and year of rolling for two years, the years selected being 1909, which marks the first considerable advance in susceptibility, and 1910, which exhibits the biggest jump in number of failures and remains the worst rolling in total fissure production.

Figure 1 presents certain fundamental unweighted data drawn from the tables. Curve A shows the increasing number of transverse fissures reported as occurring in track by calendar years. Curve B exhibits the open hearth rail production of the United States in per cent of total rail production. It will be observed that transverse fissures became a serious factor just when open hearth steel became a considerable proportion of American rail. Curve C exhibits the accumulated fissures of all annual rollings, including the rollings of 1923.

While curve A in figure 1 might superficially appear as indicating an increasing fissure menace, figure 2 exhibits as curve A the actual decreasing slope of fissure tendency in the rollings subsequent to 1911. While the rolling of 1910 now shows the largest number, it is probable that the rolling of 1911 will pick up failures to a greater total than that of 1910.

This curve has been compiled by weighting curve C shown on figure 1 by years in service, by tons in track, and by the increasing traffic densities. The weighting factors are shown in later figures. This chart indicates the real decreasing menace, and is further extremely interesting when compared with the « dream curve » and the actual curve of decrease in general rail failures from rollings over the same periods, which is shown on the same plate as curve B. Comparison inevitably draws thought toward the conclusion that general betterment in mill practice has materially decreased the tendency toward failures of all types, the effect being just as pronounced in transverse fissures as in the rest.

Figure 3 exhibits the various weighting factors used in compiling the data for curve A on figure 2. The principal factor in influencing the final result is curve A, showing the average annual number of failures of any age of rail in track. While the curve shows a gentle slope after the sixth year, it must be realized that on Eastern roads much of the rail is out of track by the end of the

Table No. 5.

Total number of known heats displaying simple transverse fissures, from date rolled to 1923, inclusive, by mills.

Number of fissure heats segregated as to number of fissures per heat by mills.

Total simple transverse fissures by mills.

KNOWN HEATS.	Unknown.	Lorain.	German.	Inland.	Bethlehem.	Tennessee.	Pennsylvania.	Maryland.	Lackawanna.	Cambria.	Illinois.	Colorado.	Dominion.	Algoma.	Carnegie.	All mills.	Cumulative (1).
Heats with 1 fissure each	7	4	2	4	1 238	402	365	976	892	1 114	1 471	308	28	128	263	7 202	...
— — 2 fissures	...	...	...	3	179	54	36	97	162	88	231	40	2	16	13	921	1 814
— — 3 —	...	...	...	...	62	21	9	44	70	27	109	5	...	7	2	356	893
— — 4 —	...	...	...	...	41	14	8	25	45	16	68	1	...	6	1	225	537
— — 5 —	...	...	...	...	24	1	3	17	25	13	27	2	...	4	...	116	312
— — 6 —	...	...	...	...	17	1	4	8	17	3	15	1	1	1	...	68	196
— — 7 —	...	...	...	...	14	...	...	6	11	1	7	...	...	...	...	39	128
— — 8 —	...	...	..	...	8	1	...	2	7	...	5	...	...	...	...	23	89
— — 9 —	...	...	...	...	6	...	...	4	7	2	1	...	...	...	...	20	66
— — 10 —	...	...	...	...	2	...	...	1	2	...	4	...	...	...	...	9	46
— — 11 —	...	...	..	...	3	...	1	2	...	...	5	...	...	...	...	11	37
— — 12 —	...	...	...	...	3	...	...	1	1	1	2	...	...	...	...	8	26
— — 13 —	...	...	...	...	2	...	...	...	1	...	...	...	...	...	...	3	18
— — 14 —	...	...	...	...	1	...	...	...	2	...	1	...	...	...	...	4	15
— — 15 —	...	...	...	...	1	...	...	1	1	...	2	...	...	..	...	5	11
— — 16 —	...	...	...	...	...	...	...	...	...	...	1	...	...	...	...	1	6
— — 17 —	...	...	...	...	1	...	...	...	...	...	1	...	...	...	...	2	5
— — 18 —	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	0	3
— — 19 —	...	...	...	...	1	...	...	...	...	...	...	...	...	...	...	1	3
— — 20 —	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	0	2
— — 21 —	...	...	...	...	...	...	..	...	...	...	...	...	...	...	...	0	2
— — 22 —	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	0	2
— — 23 —	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	0	2
— — 24 —	...	...	...	...	...	...	...	...	1	...	...	...	...	...	...	1	2
— — 25 —	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	0	1
— — 26 —	...	...	..	...	...	...	...	...	...	...	1	...	...	...	...	1	1
Total fissured heats.	7	4	2	7	1 603	494	426	1 184	1 244	1 265	1 951	357	31	162	279	9 016	...
Total fissures.	7	4	2	10	2 564	648	546	1 688	2 141	1 555	3 077	423	38	231	299	13 233	...

(1) These numbers are obtained by subtracting 7 202, 7 202 + 921, etc., in turn from 9 016. (*Editor's note.*)

TABLE No. 6.

Table showing distribution by railroads of rail in track of 1909 and 1910 rollings of three mills and corresponding fissure failures.

Tons of rail reported on by roads in per cent of total tons reported on by all roads.

Mill	Illinois.		Bethlehem.		Carnegie.	
Year rolled	1909	1910	1909	1910	1909	1910
Atchison, Topeka & Santa Fe	34.4	29.9	...	...	...	...
Boston & Maine	...	...	14.0	22.2	...	...
Buffalo, Rochester & Pittsburgh	...	...	...	...	0.0	3.8
Cleveland, Cincinnati, Chicago & St. Louis	2.3	3.8	...	...	...	...
Chicago, Rock Island & Pacific	19.1	11.8	...	...	...	...
El Paso & Southwestern	...	...	21.1	0.0	...	...
Erie	0.6	0.4	11.2	0.0	6.9	11.9
Grand Trunk (West)	0.0	1.0	...	...	2.2	0.0
Illinois Central	0.0	2.4	...	...	...	...
Indiana Harbor Belt	0.4	0.0	...	...	...	...
Long Island	...	...	0.0	18.1	...	...
Missouri-Kansas-Texas	5.7	4.4	...	...	...	...
New York, Chicago & St. Louis	2.3	1.0	...	...	...	...
Northern Pacific	14.7	17.5	0.0	6.2	0.0	16.8
New York Central (West)	10.7	9.7	...	...	...	...
Norfolk & Western	0.0	4.5	7.0	13.6	4.1	21.4
New York, New Haven & Hartford	...	...	18.7	18.9	...	...
Union Pacific	0.0	9.1	...	...	...	...
Pennsylvania	9.8	4.5	28.0	21.0	86.8	46.1
Total tons	226 083	308 811	35 692	40 495	73 246	70 011
Increase over 1909	...	37 %	...	13 %	...	— 4 %
Per cent open hearth tons to total	61 %	78 %	100 %	100 %	91 %	68 %
Increase in average traffic density	...	...	...	...	...	...
Date rolled, to 1923, inclusive	...	...	...	...	...	...
Average for U. S. classes I and II roads	...	2 %	...	2 %	...	2 %
Fissured heats to 1923, inclusive	126	708	696	258	7	2
Fissures to 1923, inclusive	212	1 004	982	393	7	2
Fissures per 10 000 tons	9.4	32.6	275.1	97.1	1.0	0.3

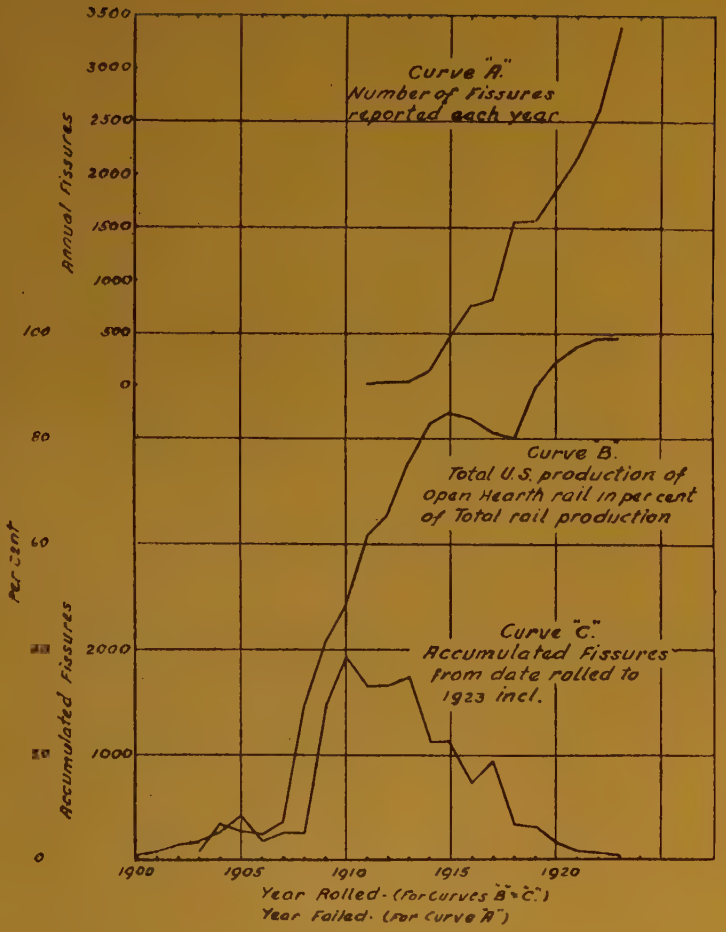


Fig. 1. — Unweighted statistics.

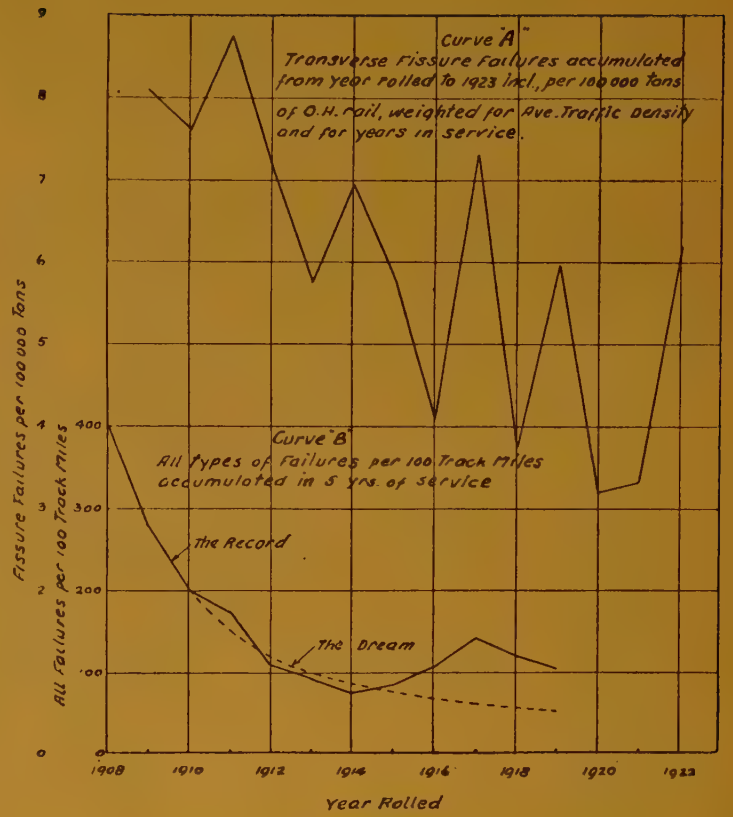

Curve "A"
Transverse Fissure Failures accumulated
from year rolled to 1923 incl., per 100 000 tons
of O.H. rail, weighted for Ave. Traffic Density
and for years in service.
Curve "B"
All types of Failures per 100 Track Miles
accumulated in 5 yrs. of service
The Record
The Dream
Fissure Failures per 100 000 Tons
All Failures per 100 Track Miles
Year Rolled

Fig. 2. — Comparison of fissure failures with failures of all types.

sixth year, while on Western roads little of the rail comes out of track before about the eleventh year. The next most important factor is the curve showing the increasing traffic densities over the last fifteen years.

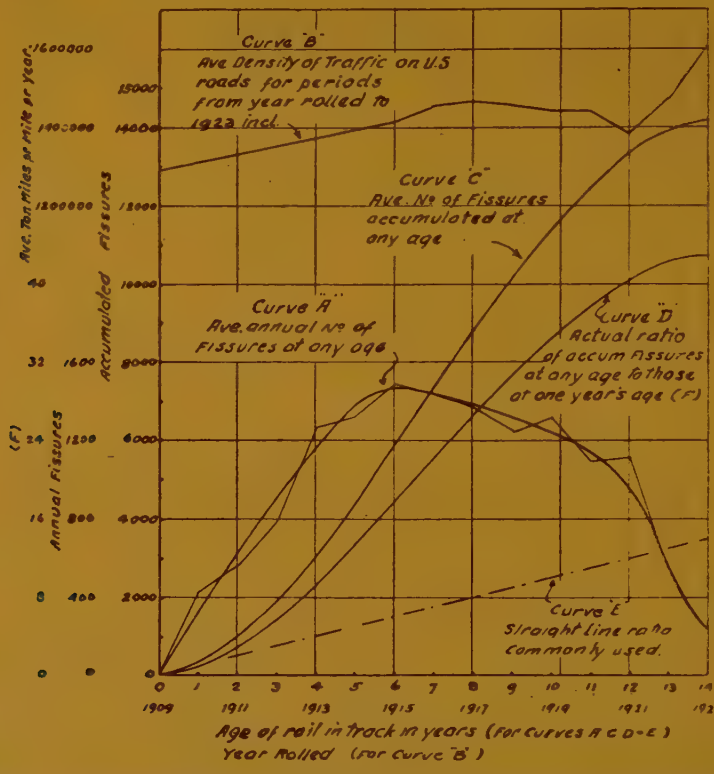

Curve "B"
Ave Density of Traffic on U.S roads for periods from year rolled to 1923 incl.
Curve "C"
Ave. No of Fissures accumulated at any age
Curve "A"
Ave. annual No of Fissures at any age
Curve "D"
Actual ratio of accum Fissures at any age to those at one year's age (F)
Curve "E"
Straight line ratio commonly used.
Ave. Ton Miles per mile per year
Accumulated Fissures
Annual Fissures (F)
Age of rail in track in years (for curves A C D-E)
Year Rolled (for Curve "B")

Fig. 3. — Development of weighting factors for increase in average traffic density and for years in service.

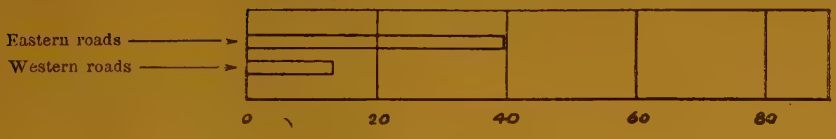
Figure 4 exhibits fundamental data as to the relative fissure production from susceptible heats in Eastern and Western traffic over a period of the first six years of life. It further shows the comparative records of life service of three years' rollings in Eastern traffic, Middle Western traffic, and Western traffic. This comparison emphasizes the relation that intensity of load and number of repetitions bears to the development of a fissure from its pre-existent nucleus.

Figure 5 follows figure 2 in exhibiting another striking similarity between the general rail fissure data and the transverse fissure data. It rates the mills both as to fissures and rail failures in general over the same rollings.

The following roads report no failures :

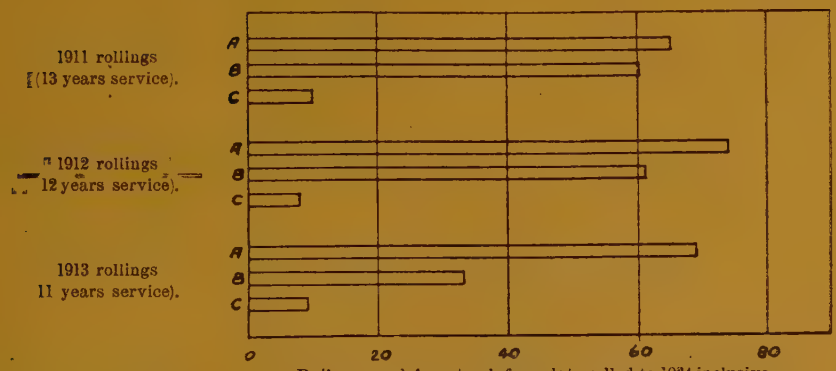
Atlantic Coast Line;
Bessemer & Lake Erie;
Baltimore, Chesapeake & Atlantic;
Grand Trunk;
Mobile & Ohio;
Rutland;
Spokane, Portland & Seattle;
Ulster & Delaware.

Percentage of total fissure failures accumulated to 1923 inclusive, that occurred in the first six years of service of rail rolled in 1909 to 1917 inclusive.



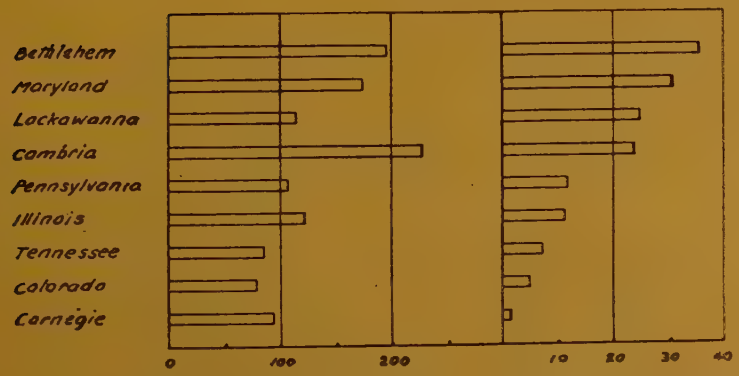
Comparative loss of rail from track due to rail wear and failure.

A = Representative Eastern heavy traffic roads.
B = — Middle Western —
C = — Western —



Rail removal from track from date rolled to 1924 inclusive, in per cent of amount laid,

Fig. 4.



Accumulated failures, all types, in five years service, per 100 track miles. Average for rollings of 1908 to 1918 inclusive.

Accumulated fissure failures from year rolled to 1923 inclusive, per 10 000 tons of rail of rollings of 1909 to 1920 inclusive.

Fig. 5. — Rating of mills.

The following roads keep no record covering interior fissure failures :

Atlanta & West Point;
Chicago, Indianapolis & Louisville;
Colorado & Southern;
Chicago Junction;
Bangor & Aroostook;
Florida East Coast;
Kansas City Southern;
Lake Erie & Western;
Maine Central;
Minneapolis & St. Louis;
Pere Marquette;
Pittsburgh & Lake Erie;
Richmond, Fredericksburg & Potomac;
Temiskaming & Northern Ontario;
Toledo, Peoria & Western;
Toronto, Hamilton & Buffalo;
Wheeling & Lake Erie;
Central Railroad of New Jersey;
Chicago & Alton;
Chicago & Eastern Illinois;
Chicago & North Western;
Chicago Great Western;
Delaware & Hudson;
Denver & Rio Grande Western;
St. Louis-San Francisco;
Western Maryland;
Great Northern.

Extract from the report of the Rail Committee of the American Railway Association.
(Appendix B.)

Rail failure statistics for 1923.

By J. B. EMERSON,
ENGINEER OF TESTS, RAIL COMMITTEE.

This report deals with the rail failure statistics for year ending 31 October 1923. The information furnished by the reporting railways remains precisely the same as in foregoing reports, including as a standard method the system undertaken last year of basing the failure rate on the amount of rail actually in track through the observation period. This is accomplished by the use of mile years of service in track rather than years only, which obtained up to last year as a regular system.

The original compilation and tabulation does not give consideration to the varying traffic conditions under which the rails are called upon to serve. The Rail Committee has worked for several years with scant success on a system of rating rail performance by the tonnage carried by the failed rail. It appears that this tonnage is not accessible for any substantial proportion of the failures.

This year another angle of the traffic element has been considered and there is presented in this report a chart, figure 9, rating the comparative performance of the various mills by including in the compilation due regard to the average ton miles of revenue freight per mile of track of the various railways into whose tracks the output of these mills was placed. This chart is presented simply as information, and the Committee has not yet decided to use this method for compiling general statistics in future.

No claim is made for the entire accuracy of this system of rating, but it does give more consideration to the work the failed rails from the respective mills are called upon to perform than heretofore. Should the general idea meet with favor, the traffic density factors may be corrected yearly from the Bureau of Economics reports, and also to include consideration of the locomotive ton miles, work train service, and the passenger train miles. No change would be neces-

sary in the present system of reporting failures, as the use of the factor would be confined to the compilation of the report to the Association in the office of the Engineer of Tests.

Authorized rail failure statistics for 1923.

The rollings for 1918 and succeeding years are embodied in these statistics. The tonnage and track miles represented are as follows :

Year rolled.	Tons	Track miles.
1918	863 683	5 756.11
1919	954 575	6 388.57
1920	1 086 196	7 200.83
1921	1 116 634	7 338.52
1922	1 109 007	7 116.16
1923	768 640	4 819.63

The average results are shown in the following table, together with the results taken from previous reports. The measure of performance of each year's rolling is taken as the failure per 100 track miles for five years' service. As indicated in our last year's report, the 1918 rollings, whose period of observation is now concluded, exhibits a substantial drop in the curve which has been ascending since the rollings of 1914. The peak of bad performance has undoubtedly been passed, although the four year record of the 1919 rollings indicates that next year the failures will be slightly higher than this year, although still below the peak of the 1917 record.

Figure 6 shows diagrammatically the general average results, and the failures of the rollings from each of the mills are shown in figure 7.

The failures per 100 track miles per year of service are shown in figure 8. Illinois now shows the least failures with a figure of 11.19, Carnegie and Algoma run them a close race with figures of 11.65 and 12.35 respectively.

Average failures per 100 track miles.

YEAR ROLLED.	YEARS SERVICE.					
	0	1	2	3	4	5
1908	...	...	...	...	...	398.1
1909	...	...	...	...	224.1	277.8
1910	...	...	...	124.0	152.7	198.5
1911	...	...	77.0	104.4	133.3	176.3
1912	...	28.9	32.1	49.3	78.9	107.1
1913	2.0	12.5	25.8	44.8	69.5	91.9
1914	1.2	8.2	19.8	32.9	50.9	74.0
1915	0.7	8.9	19.0	34.2	53.0	82.4
1916	1.6	11.8	29.2	47.7	70.6	105.4
1917	5.3	21.6	38.9	66.0	110.5	137.0
1918	1.6	8.9	27.6	54.0	92.8	125.4
1919	2.0	14.8	39.4	73.7	104.8	...
1920	3.9	14.2	32.4	63.1	...	...
1921	1.6	10.9	34.9	...	...	. .
1922	1.5	15.9	...	...	...	...
1923	3.7	...	...	...	...	...

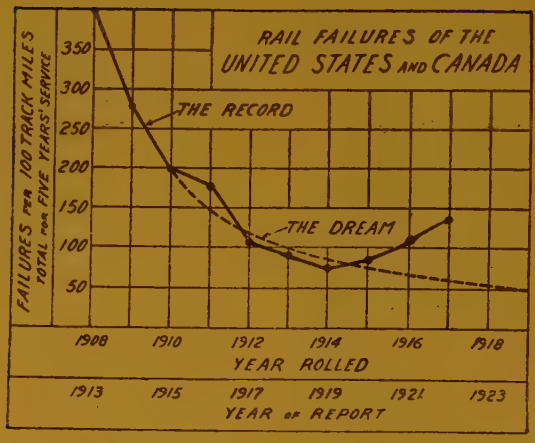


Fig. 6.

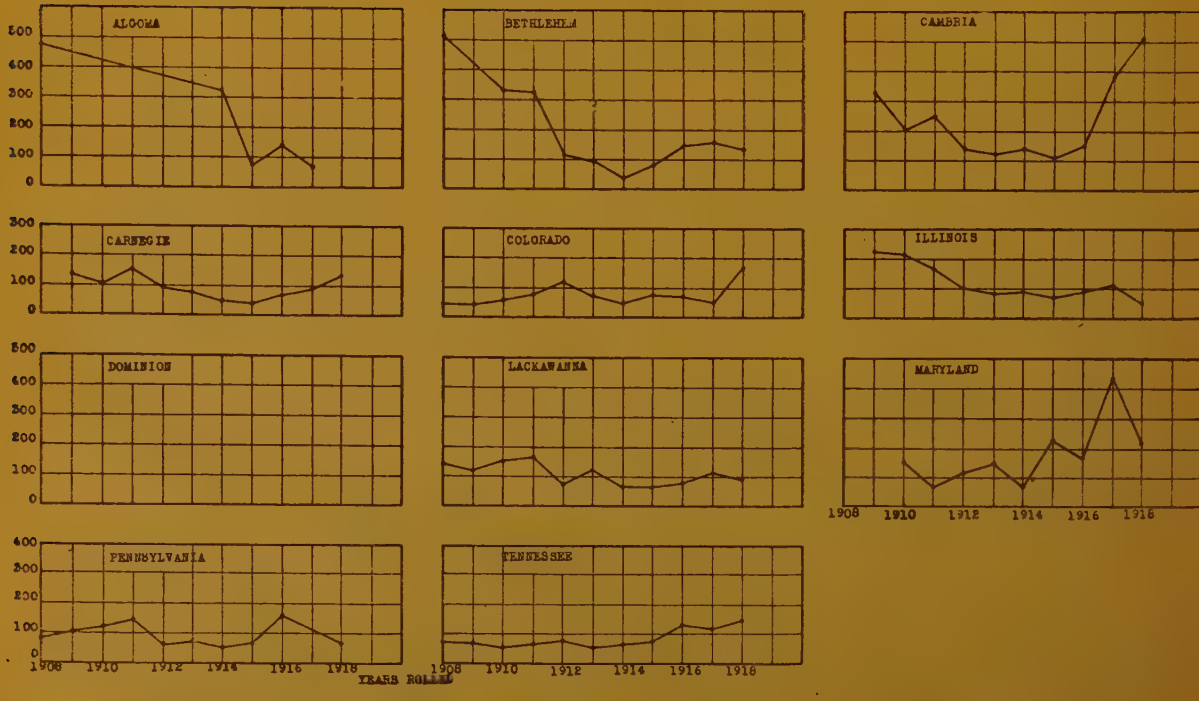


Fig. 7. — Failures per 100 track miles. Total for five years' period.

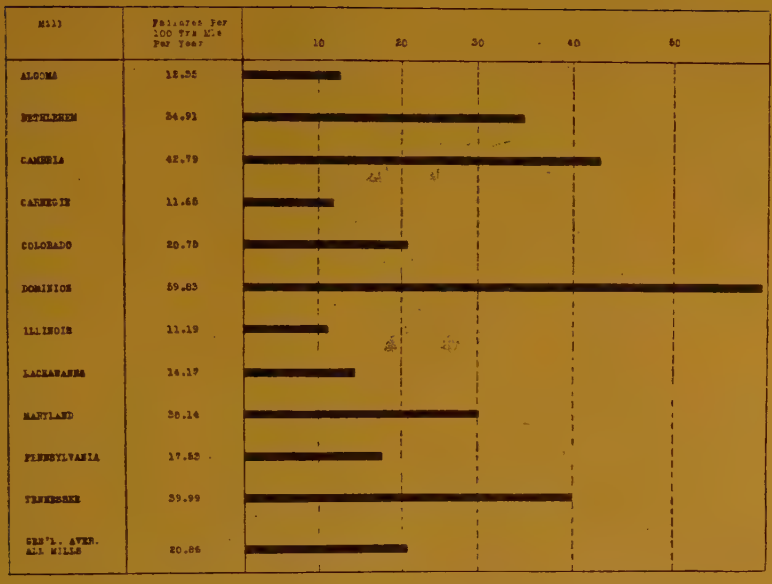


Diagram showing mill ratings for five-year period compiled by usual method.

Fig. 8. — Average failures classified by mills for the rollings from 1918 to 1922 inclusive.

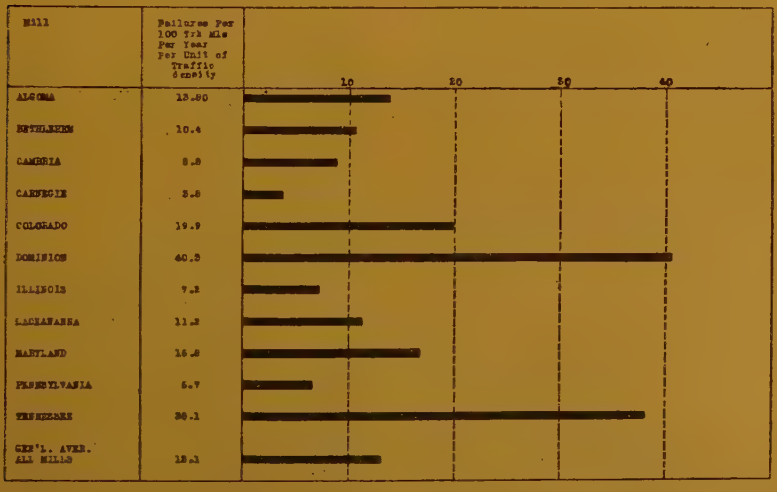


Diagram showing mill ratings for five-year period as altered by use of traffic density factor.

Fig. 9. — This diagram is presented for information only and shows ratios changed from those presented in figure 8.

62. (01 & 625 .143.2]

Interior fissures in rails, with oval marks.

Theories on their formation,

By Louis PICHARD,
ENGINEER OF « ARTS AND MANUFACTURES ».

Figs. 1 to 13, pp. 687 to 694.

(*Le Génie Civil.*)

A. Theory of the first interruption in continuity without there being any definite internal defect. — 1. *Considerations on homogeneousness and heterogeneity in a rail.* — Let us in imagination take a very short piece of rail, 3 to 4 cm. (1 3/16 to 1 1/2 inches) long cut lengthwise for example. Without thinking that the real structure of the metal allows such a division, we will consider this piece of rail as made up of a very large number of longitudinal fibres adhering together. This done, in each part of the rail there are four kinds of homogeneousness to be considered, *viz.* :

« 1. *Chemical* : same composition at each point;

« 2. *Thermic* : same heat treatment of each grain subsequent to the solidification of the metal;

« 3. *Physical* : same degree of working in rolling, etc.;

« 4. *Mechanical* : mechanical equilibrium in no matter what part of the rail; no internal stresses. »

To what extent, from these four aspects, can this rail be considered to be homogeneous ?

Obviously chemical homogeneousness is very rarely found. Thermic homogeousness is never obtained, the cooling of any point being always a function of its distance away from the outside and from neighbouring masses. From this fact mechanical homogeneousness also is never realised because at any given moment during cooling, the possibility of contraction of the different parts of the rail, being a function of the reserve of heat units therein, varies, although as these parts make up the same solid they should contract in the same measure. From this, those parts that were hottest are left permanently in stress (cubic stress, imaginary elongation) (1), whereas in the coldest parts are to be found internal compressions. Finally, when the rail is

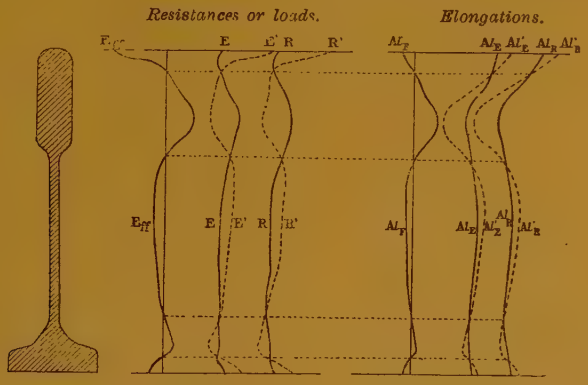
(1) Cubic stress, imaginary elongation. The cubic stress arises both directly and indirectly : in fact the tendency to contract acts and gives rises to stress in all directions whereas the unsatisfied desire to contract should be considered as an imaginary elongation; on the other hand, there is a reaction of the phenomenon from one direction in all the others; in point of fact, under a stress tending to lengthen it, a fibre, a cylindrical element if you like, endeavours to reduce itself in itself, this being more noticeable as the elastic limit is passed when a reduction in area occurs. In this case there can be no reduction in the heart of the metal which is, if we may say so, « negatively bound together ». The result is that as the imaginary elongation occurs in one direction, stresses are created in all directions in the plane perpendicular to the principal initial stress.

rolled obviously physical homogeneousness (in manufacture) is also not realised.

2. *Graphical representation of the heterogeneity of the small piece of rail.* — It may be agreed that whilst any fibre is chemically, thermically, physically, and mechanically homogeneous, from one fibre to another there can be considerable difference in quality.

The heterogeneity can be shewn by curves giving the values of these qualities according to the point of rail considered : for simplicity, only points on the axial plane of the rail will be considered. This laid down, we have representative curves of :

E, elastic limit (fig. 1) ; R, breaking strength (fig. 1) ; AL_E, maximum elastic extension (fig. 2) ; AL_R, absolute extension at fracture (fig. 2).



Figs. 1 and 2. — Curves giving generally the variations of the resistances and of the elongations in the different parts of a rail.

We also have the curve of the internal stresses : E_{ff} (fig. 1) tension on the right, and the curve of the imaginary elongation AL_f, corresponding to these same internal stresses, which gives the amount of contraction (or of extension) which takes place in any fibre considered if the tension (or the compression) in it should disappear, that is to say, in the event of its being separated from the mass of the other fibres, or if it were restored to a state of rest (fig. 2).

It must be noted that the curves on the diagrams have not been drawn haphazardly. In fact :

1. Segregation is a maximum at the centre of the ingot which here corresponds to the area common to the head and web of the rail, R ought then to be a maximum at this point and at the same time AL_A is there at a minimum ;

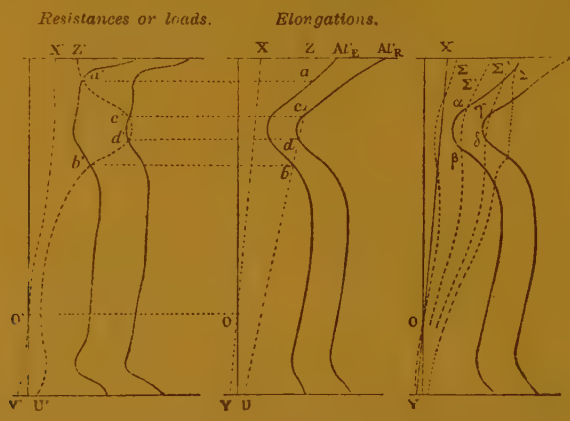
2. Approaching the outside where the cooling of the ingot is quicker and consequently the grain is finer, R and E increase ;

3. Work has been done on the surface of a rail in service by the trains that have passed over it ; this increases R ;

4. At this same point the cold rolling, due to the same cause, gives rises to compressions, a small part of which is taken up by deformation of the surface, whilst the remainder persists, and, in order that there be equilibrium, causes stresses in the underlying layers ;

5. The heart of the head, being the hottest part when the rail leaves the finishing rolls, has at this moment the greatest capacity for contraction : consequently, it becomes the seat of internal stresses : whence E_{ff} maximum. For the same reason, a relative maximum E_{ff} is found at the bottom of the web.

Once this is understood, the curves AL_E and AL_R have been drawn expressly for metal supposed to be in a state of repose. But, owing to the existence of the imaginary elongations, everything takes place as if there remained as capacity for extension only the difference of the ordinates between the curves AL_E and AL_F on the one hand, and AL_R and AL_F on the other; or as if we only had the capacity for extension given by the curves AL'_E and AL'_R obtained by graphical subtraction of AL_F from the two initial curves, and it is on these two particular curves AL'_E and AL'_R (fig. 4) that we intend to base our argument.



Figs. 3 to 5. — Deformations imposed on a rail when the elastic limit or breaking stress is exceeded at certain points.

Finally, although the sequence of the phenomena is more easily understood from the diagram on which E, R and E_{ff} are shewn, we are led to be consistent to consider the diagrams E' and R' deduced from E and from R by graphical subtraction of E_{ff}; we have shewn separately these two new curves on figure 3.

3. *The consequences resulting from any deformation of the small piece of rail.* — Suppose that the 3 to 4 cm. (1 3/16 to 1 1/2 inches) length of rail be actually separated from the rest of the rail without, as the result of this separation, the distribution of internal stresses being affected, and each of its end faces then welded to the side of a perfectly rigid body. If one of these bodies be inclined relatively to the other, we can extend all the fibres in the small piece of rail in accordance with a simple formula On the diagram to the same scale we should get the straight line XOY (fig. 4).

If the relative movement of the two bodies be increased until the straight line ZU on the diagram was obtained, it is clear that the elastic limit of all the fibres in the region *ab*, has been exceeded : these fibres have therefore had work done on them on a certain part of their length; finally, for the fibres in the region *cd*, in which the breaking extension has been exceeded, we have undoubtedly a failure somewhere, but the fracture which occurs remains localised, if we do not carry too far the relative displacement of the two bodies.

If we note that for any imposed elongation there is a corresponding load or tension, we can construct on the diagram, figure 3, the curves X"OY' and Z'U' corresponding to the elongations defined by XY on the one hand, and by ZU on the other (fig. 4). The same conclusions can be deduced therefrom.

In practice, it would be quite unusual

to find one or two sections so secured as to remain straight under the loads to which the rails are subjected; there is, however, one particular case in which this occurs, that of the shock test of sections of rails : if we consider the section of rail which has on its periphery the centre of percussion of the falling weight, it should be noted that owing to its symmetry, the section remains flat (1). Once fracture starts, if the kinetic energy left is sufficient, the rail will break into two.

4. *Modification of the theory enunciated above in order to make it agree with practice.* — It is known that in practice the sections of the parts are not so held as to remain flat, and that as they are adhering one to another, the fibres of a piece support each other or bend together. We can believe that the fibres which are most heavily stressed for any given extension of the whole do not lengthen to the extent expected of them, and from this fact carry a lighter load, whilst the remainder are more heavily loaded; the result is the deformation of the sections which become hollowed out as it were at the point where the elongation has been too small.

This point of view can be shewn on the diagram of the elongations (fig 5) which can then be taken as representing a short part of a rail of indeterminate length, under a given stress.

In place of the straight line XOY of the previous case, we shall have the curve Σ for example, definitely influenced by the quality of the metal. If the work done in tension in this part of the piece increase, Σ becomes farther away from the axis of the abscissæ : if it (curve Σ′) should cut at α and β the curve of the elastic extensions, the reason is that a group of fibres of the piece has had work done on it in a given region, and this work continues and extends on a given fibre as we get away from the point where it commenced, that is to say, as the tension is increased. If by increasing the load, a still greater tension were imposed, that is to say, a still greater elongation, the curve Σ would end by meeting (curve Σ″) the curve of the AL'_R's at γ and δ, and the fibres in the region corresponding to γδ would break. These fibres would then do no more work, and the result of their failure would be an increase in the work to be done by all the others, whence a new extension of the whole : the curve Σ″ will have to be replaced by the curve Σ‴ in *two sections*, and it is possible that there may be a position of equilibrium at which the fracture would extend no further

It is highly probable that such cases of failure of the characteristics E, AL_E, AL_R, are rare; however, the fact can be admitted and explains the beginning of transverse fissures in a rail in which is then found the oval mark without any other defect than that of heterogeneity being discovered.

In general, such fissuring is assisted in the mass of the metal by the presence of impurities more or less voluminous or even by cavities which break the continuity of certain fibres, the neighbouring fibres then become overloaded, extend still more, and the points γ and δ (fig. 5) are reached for a total amount of work relatively unimportant.

We will now consider the causes of mechanical damage having such consequences.

B. Commencement of mechanical damage in the rails during rolling. — 1. *Internal cracks.* — In an investigation into the oval mark made by Mr. Fremont and published in the *Génie Civil* of the 24 October 1925(1),

(1) Whether fracture occur or not, the head of the rail is subjected to very high stresses, and the elongation imposed always exceeds the elastic elongation as the rail always takes a permanent set. If fracture occur, it is because at some point the breaking stress has been exceeded, that the points *c* and *d* or *d* undoubtedly of our diagram exist, and that (according to the case), a centre (internal or surface) of fracture has been formed.

(1) See the *Génie Civil* (vol. LXXXVII, No. 17, p. 349).

many photographs were given of the rail on which we have based our theory of the internal crack caused by rolling (figs. 3, 4 and 5); we give below therefore the original wording of our explanation thereof :

« The section of rail broken in service shews two breaks with many oval marks about 115 mm. (4 1/2 inches) apart. The macrograph shews the existence of a much segregated area surrounded by a zone with two secondary areas of impurities. The piece between the two breaks, cut parallel to the rolling surface and 15 mm. (19/32 inch) from it, was macrographed. It is seen that the main segregated patch contains a large number of cavities.

« What are these cavities? They are not blow holes which, formed before the complete solidification of the metal, should after rolling be reed like in appearance; they are also not due to piping; like the blow holes, these ought to be reed like, and these cavities have not such an appearance; on the contrary it seems that the transverse dimension is the greater in them all, and also they are in line transversely.

« Finally, it seems that the outside zone is affected where these cavities are located; the lines which represent it actually bend in at these points.

« Any such repercussion can only occur prior to the completion of rolling. Therefore the cavities are due to the rolling itself.

« The following hypothesis can be put forward : shortly before the rolling is finished the metal in the core becomes barely ductile, whilst the surrounding sleeve is still ductile. During a further pass, the rail lengthens, the sleeve lengthens and becomes thinner, the central core resists the compression and is only slightly reduced. However, it adheres to the sleeve over its whole surface, and lengthens in the same way. The result is that it is subjected to severe longitudinal tensile stresses to which its weaker parts yield : it cracks in certain sections.

« In conclusion, each cavity or each group of cavities in line transversely would be in a region of the core *overstretched* at a given instant, and possibly permanently stressed which would facilitate the formation of a complete transverse fissure in the core. »

Other examples of internal cracks of sharply marked appearance, but of much smaller dimensions, were found subsequently and correspond with rails broken in service.

2. *Similarity of this hypothesis and the explanation of transverse fissures by the simple heterogeneity of the metal.* — We have seen that the cracks may be caused in rolling. The difference in ductility may be insufficient for this to occur. There may result simply the formation of overstressed zones which will be, apart from other causes of heterogeneity, predestined to fail.

3. *Shrinkage crack.* — This damage is well known, but it is necessary to mention it here to explain its origin with the help of the graphical representation of the heterogeneity.

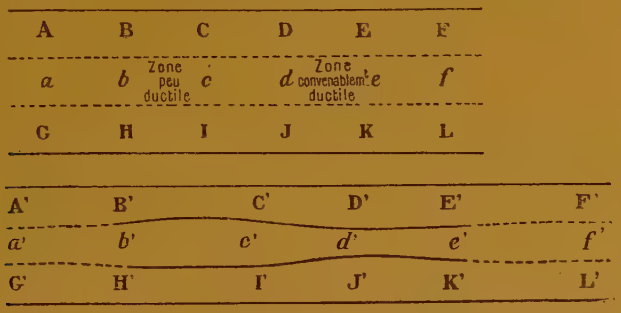
Returning to figures 1 and 2 : the curves representing the internal stresses E_{ff} and the imaginary elongations AL_F have been drawn as they are at all points, one below the curve R (breaking strength), the other below the curve AL_R (breaking elongation); if it were not so, it would imply that somewhere the unmet need to contract had become greater than the elongation at breaking and in consequence there had been a fracture. This is the shrinkage crack.

4. *Detachment of the centre segregated mass along part of its circumference.* — By the same theory of a difference in ductility between the sleeve and the core, a very different result can be arrived at. Suppose an instant when, although little ductile at a point, the segregated central core of the future rail, or rather its end, is more so at a nearby point; we can agree that this latter zone supports almost alone the extension imposed on it by the sleeve.

Then it will cause a separation of the core about its periphery to occur over a certain length.

On the other hand, at the place where the core lengthens, the sleeve extends less because there is less metal to become reduced owing to its thinness.

Let ABC... F... KL be the sleeve, and *a*, *b*.:. *f* the barely ductile core in the zone *bc* and normally ductile at *de* (fig. 6), whilst the zones *ab* and *ef* are the zones permanently attached to the sleeve, that is to say, of which the composition and adherence to the surrounding metal are such as to prevent any defect to develop as the result of internal stresses. After a pass through the rolls, BC becomes B′C′; CD becomes C′D′, etc. (fig. 7). The elongation is as a whole the same for the sleeve as for the core; only the part to the left *bc* has slightly altered and the sleeve has become extremely thin; in the right-hand part DE or JK of the sleeve has little changed in thickness, and it is *d′e′* of the core that has most extended. The core has become « unboxed » from *b* to *e* in fact.



Figs. 6 and 7. — Zones overstretched as a result of rolling.

Explanation of French terms:
Zone peu ductile = Zone little ductile. — Zone convenablement ductile = Zone normally ductile.

It is certain that any such accident will not take place during one pass; first of all undoubtedly tensible stresses will occur in a certain part of the metal surrounding the core; at the next pass certain particles in this metal will separate, and at the last the separation can be quite definite.

The separation is never annular and the slip is not great because of the interlocking of the core and the sleeve by the web where their respective extensions are very much worked and, consequently, attain a better quality enabling them to assure this interlocking.

This last hypothesis also enables us to explain the breakages due to a detachment of part of the rail head; above the zone of slip, during the passage of vehicles, fissures grow towards the sides of the head

C. Commencement of transverse fissuring in service. Origin of the oval mark — 1. *Case of a rail simply heterogeneous.* — The description of this commencement of fissuring has been given in the first part A of this investigation.

When the work done in the whole section is normal some fibres more particularly defective and overloaded, have been caused to break. Starting from this stage, every argument that will be developed below could also be applied to this first case.

2. *Case of an internal crack or of a seam. Dynamic effect.* — If the reactions of the sleepers supporting a rail could be known or measured, it would be possible to establish the influence line of this rail for each of its sections: as they cannot be.

we must be satisfied to reason it out.

Let us note, first of all, that it would be sufficient if we knew the solution of the problem for the two sections : section half way between two sleepers, and section above a sleeper.

In these two cases, during the approach, passage, and departure of the load, the head is submitted in turn to tension, to compression, and to tension, stresses. In particular, if we are considering a section above a sleeper, during the approach of the load, the reaction of the sleeper starts and increases (1), the head of the rail yields; when the wheel comes over the sleeper, this latter only takes part of the load as it always gives a little, the rail also yields slightly and as a result its centre line is deformed; whence it may be concluded that even in this particular case it works by transmitting part of the load to the neighbouring sleepers. and from this fact its head is at the point considered subjected to longitudinal compression. Subsequently, the phenomenon repeats itself symmetrically as the wheels move away.

Between the two extreme cases, there are very important differences :

1. The maxima of tension in the head are greater in a section on a sleeper than in a section between two sleepers :

2. At equal speeds of passage of the load, the maxima succeed one another more quickly in a section over a sleeper.

Consequently, the degree of stress to which the head of a rail above a sleeper is subjected is much greater than elsewhere. and this is why the fissures grow, particularly in this case, and are the first to develop fully

This stated, let us suppose a cavity exists in a section above a sleeper.

Almost instantaneously the region to the left is affected and stressed so as to endeavour to lengthen towards the left according to the method we will outline. It takes with it the region to the right by the metal surrounding the cavity, but in this region, in the case of dynamics, we should bring into account a new force which opposes the elastic displacement of the elements of the region to the right : this force is due to the inertia of the masses in this region.

In fact, if there were no cavity, the masses to the right would also follow, although possibly slightly later and the equilibrium of the forces would be established with the aid of the inertia forces; but owing to the interruption in continuity, there is a zone which is not directly stressed to the elastic displacement : its inertia holds it up first of all, and. as it adheres all round to the remainder of the piece, the inertia forces set up at its first movement still further overload the outside elements of the cavity, from which we get fissuration at the most highly stressed point (1).

3. *Case of a separation of the core.* — The surface on which slip occur has many chances of revealing certain particular points; it is not in fact certain that the boundaries of the segregated zone which gave birth to it are regular in form : in the same way as the core is not homogeneous longitudinally. there may be as it were a commencement of strangulation in the parts drawn out (it is hardly possible to speak of reduction in area at rolling temperatures). In short, we are going to load a piece which is practically double, each part shewing irregularities : further, these parts are of different qualities both when comparing one with the other, and in their own length, so that whilst in the whole there is no extraordinary stress. certain unfavoured points are over-charged, an element yields, and fissuration commences

(1) It is extremely improbable that the system of sleepers with ballast forms a sufficiently rigid whole for the case of the partial discharge of one of these supports to occur.

(1) This paragraph develops Mr. Frémont's idea, he being the first to think of the effects of inertia.

D. Growth of fissuration in a section of a rail placed above a sleeper. — 1. As has been shewn above, in a section of the rail head, the approach of a load is characterised in turn by the head being put in tension, then in compression, and finally again in tension. The first tension is produced gradually, and if a further growth of the fissure occur this can only be of a small element A*a* (fig. 8),

Fig. 8.

whilst the maximum of the second tensile loading follows suddenly on the compression caused by the passage of the load above it ; its action is therefore more marked, and the element of growth *aα* which occurs is greater than A*a*.

This differentiation between *aα* and A*a* is very important, as will now be seen ; in fact, the element of metal is not only subjected to the tension due to the bending moments, it has also to support the tangential stresses due to the shearing forces, and these latter change in direction according as the load is in front of or beyond the zone of fissures. It follows that, when superimposed on the normal stresses they make the fissuration deviate first to one side and then to the other : as a whole the fissuration places itself towards the side where the largest elements of fissuration are themselves placed, from which we may conclude that the general location of a transverse fissuration of slow growth (oval mark) is a function of the direction of running of the train.

This explains why in a rail broken in service on the Alsace-Lorraine Railways, the five oval marks that we found therein were inclined parallel to one another ; and, for the same reason, if the oval mark in the American rail of figure 9 has two zones of very different inclinations, it is probably because the fissuration is here made up of two superimposed service fissurations, the passage from the first to the second having taken place when the direction of the trains over the rail changed or when the rails were relaid after being turned.

2. *Form of the fissure.* — The quality of the metal in the first part of this investigation was represented by means of curves drawn for the centre of a rail section ; for the whole section, a different representation is required, given by drawing « lines of equal quality ». For AL_R, for example, we get for a defective section, the appearence shewn in figure 10. The starting point of fissuration is generally close to the centre of the lines of equal quality ; so that at the start, the elements of the fissure, formed at the same time, but in different directions, will be approximatively equal : the fissuration will be semi-circular. Subsequently, it becomes oval, the major axis being usually parallel to the rolling surface, as it is generally towards the top, in the beginning, that the fissuration will reach the most sound zones of metal, in which its growth will slow down, although, on the other hand, the resistance required of each fibre increases. Finally, in the case of a crack, we can note that certain particular points, such as B and C act as secondary centres of fracture (fig. 11), which also assists in making the fissuration oval.

If A, initial centre, is on the side of the head, the fissuration will be eccentric, because, on one side it will be bordered by a sound zone, which it will weaken gradually whilst, on the other, it will spread rapidly across the whole of the central defective zone of the head (fig. 9, American rail).

Finally, after the growth has passed a certain point at which the fissuration has approached its limit, close to the web,

Fig. 9. — Oval mark of a rail
shewing two zones of different inclinations.

Fig. 10.
Oval mark with a single breaking centre;
lines of equal quality.

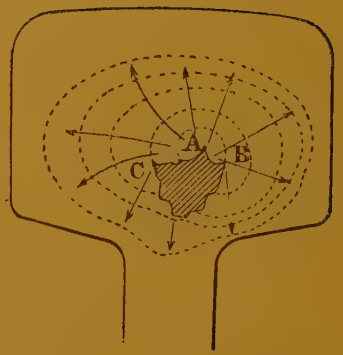
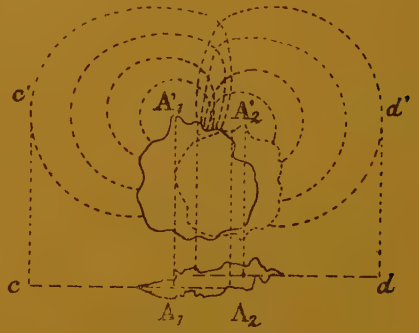


Fig. 11.
Oval mark with two secondary breaking
centres B and C.

Figs. 10 and 11. — Ovalisation of the mark.



Figs. 12 and 13. — Multiple oval marks projected on to a vertical plane,
and on to a horizontal plane.

the influence of the connecting radii, where the metal has been much worked, and is very strong, makes itself felt; the radii practically fix the extent of the fissuration, whereas it will drive a salient between the radii across the segregated part of the web.

3. *Dulling of the fissuration. — Silvery oval mark or oval mark.* — We have seen above that in any particular section, during the passage of a load, the head is in tension, then in compression, and then in tension again : in this way two eight-wheeled locomotives at 72 km. (44.7 miles) an hour submit a section over a sleeper to 32 tensions and 16 compressions in about one and a quarter seconds These tensions and compressions are dynamic : there is therefore a blow at each compression between the two faces.

If the piece were only subjected to loads normal to its surface, probably there would be no dulling, each grain refinding the place from which it came, but the piece has also to carry the shearing load which has the effect of loosening slightly one of the walls, more exactly, the central part of one of the walls as compared with the other : the loosening is extremely small, and the dulling is done very delicately : it is quite intimate if we can say so ; the details in relief are hardly changed, and the granular walls which the fissure should conserve, take the characteristic appearance of a multitude of brilliant facets, which gives it its name of silvery mark.

Every transverse fissuration by internal oval stain commences always by being a silvery oval mark, and it is due to a simple reason that they lose this appearance : it is sufficient in fact if the mark extends to the periphery and that then atmospheric elements are able to get in contact with it.

Mr. Fremont when wishing to bring out the effects of the alternating work of the rail on the existing fissuration, crystallised his thought in saying that the walls acted as bellows, but in choosing this simile he had not in mind the movement of the appliance only. In fact, with him we give this comparison its full meaning : when it has reached the periphery of the rail at a point, the fissuration acts afterwards just like a bellows which draws in and expels the air and water on the surface of the rail. In a short time, the latter element has made everything wet, and commences to tarnish the silvery walls.

We will add that Mr. Fremont has even considered the particular case of the mark, whilst still isolated from the periphery, being put into communication with a secondary cavity containing corrosive matter which would be « pumped » in similar fashion and cause the mark to lose its first appearance.

4. *Concentric coloured curves seen on certain marks.* — When at rest, the fissuration ends by remaining slightly open : the water it contains collects all over its periphery by capillarity, and the line between the liquid and the air in the centre ought by the same law, to pass through the points where the distance apart of the walls is the same. Obviously these points are situated on concentric elliptical curves : the result is that the traces of variation of corrosion are themselves elliptic, and these are the curves which complicate the appearance of the mark and are in fact quite independent of its growth, whereas it might be thought they represent stages in the growth.

As a corollary, a *silvery* oval mark ought never to shew coloured curved lines. In the same way, a multiple oval mark, that is, one made up of several pieces of fissures, should rarely shew regular coloured curved lines ; regular spacing of the curves could only be exceptional.

5. *Multiple oval marks.* — Above we have taken the oval mark as starting from a single point A of the periphery of the cavity. It can also be imagined that the form of the cavity may be so involved that

two or more points, such as A, exist in nearly transverse planes. Suppose, for example, A_1 and A_2, these points not on the same fibre (figs. 12 and 13). When, on projecting them on to a transverse plane, the two fissures have a common part, they will influence each other directly as to their growth, and then each of them will in turn protect a part of the other from the load tending to open them.

The small isthmus of metal between the two common parts will be subjected to high tangential stresses longitudinally, and it may be will yield before the complete fracture of the rail, leaving in this event, signs of an important tear in the « multiple oval mark ». Otherwise, it will yield when total failure occurs, and will be distinguishable by its bright and fine grained fracture in the middle of the dulled and silvery mark or the dulled and coloured mark.

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The organisation of a stores department, (1)

By H. MARSH,

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(*The Railway Gazette.*)

The service that the railway stores department gives is the service of supply. Accordingly, it is necessary to insist on the importance of the distribution side. The present financial position of the railways is such as to render it necessary to keep expenditure down to a minimum. The stores superintendent — and his lieutenants, the « section » storekeepers — may be excused, therefore, for imagining that their principal duty is to reduce stock. It is not. The storekeeper's job is to keep stores. Of what use is it to save the railway company 5 % on material, and at the same time cost it 10 % in delayed work and unnecessary labour? Failure to supply what is needed may well be reflected in a serious dislocation of the revenue-earning organisation.

There is no department that directly expends so large a part of the gross earnings of the railway as does the stores department. A manufacturing plant in which the plant merely equalled in value the annual output would be regarded as having a relatively large fixed investment. But in the case of a railway, on a post-war basis, the plant is five times as great in value as the annual turn-over!

In addition to efficient purchasing methods, the stores department system must provide for the proper care of supplies. Modern, well-arranged, and convenient buildings are desirable, so that supplies may be housed in good order. Due regard must also be paid to the manner of issuing stores and to the method of accounting. It requires no argument to show the necessity for a satisfactory basis of accounting for materials and supplies which will provide for appropriate financial and statistical records.

The stores department being essentially a specialist organisation, the scheme of administration must manifestly be devised on departmental lines.

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(1) Abstract of a paper recently read at a meeting of the Swindon Engineering Society.

The departmental headquarters, it should be mentioned, will ordinarily be located, not at the general headquarters of the company, but at the principal manufacturing and repairing centre, obviously a very convenient arrangement. At this local centre the stores executive, together with the clerical staff, will be accommodated. The stores superintendent is customarily supported by two or more principal assistants, whose functions embrace the purchase of materials and supplies, staff matters, and various general duties of a supervisory nature. Travelling down the executive scale, the next grade of officials will consist of the stores accountant, the head of the inspection department (if any), and the various sectional storekeepers, who will each maintain their own staffs. In regard to inspection work, it is suggested that the most satisfactory method is to set up an inspection branch, with a competent technical staff, as an integral part of the stores organisation itself. The head of the inspection department will therefore be responsible for seeing that the material purchased is of the required quality.

The section storekeepers may be said to form the backbone of the stores department. A railway undertaking naturally covers a large area, and the department, as well as being organised from the standpoint of meeting the demands of the manufacturing and repairing works, must also be so devised as to cater effectively for the needs of the stations and depots up and down the railway system. At the company's principal constructional centre, although the head office staff remains as a distinct entity, the operative side of the stores organisation will probably be split up into three or more sections, each in charge of a storekeeper : thus locomotive, carriage and wagon, traffic and general sections. These sections, in turn, will be sub-divided into a number of warehouses, which serve the larger workshops, the needs of the smaller shops usually being met by satellite storehouses, who rely to a great extent for their supplies on the « parent » warehouses.

The controlling storekeeper, whether it be of the locomotive, or carriage and wagon, or other sections, has his own office staff, who are concerned principally with the maintenance of the sectional stock records. Each warehouse within the section (and there may be 20 or more, according to the number of shops served) will be in the charge of a warehouseman, with, possibly, one or more assistants. The personnel of a large warehouse may consist of as many as 6 to 10 issuers, together with a number of « storesmen, » who will be engaged mainly on cartage work. It should be borne in mind that the storehouse strength must be such that an adequate « issuing » staff is available when night shifts are worked by the shop or shops to which it is attached.

A large number of the out-station operating depots obtain their supplies direct from stores headquarters. This arrangement, however, is not always convenient, and the stores organisation frequently provides for several « out-storehouses, » designed to serve the districts farthest away from the centre. Again, it may be found necessary to deal with the supplies for the signalling, train lighting, and other specialist branches, by means of out-storehouses attached to these depots. Nevertheless, it should be said that, consequent upon the railway grouping, there has been in the stores department, as elsewhere, an increasing tendency to centralisation. At the same time there are obvious limits to the process of concentration at headquarters. The ultimate test must be whether the service of supply provided in the case of the out-station depots is an adequate one, whatever their geographical situation or the special nature of their requirements.

In dealing with the local workshops and the out-station depots the section storekeeper is entitled to rely to a large extent upon his warehousemen. The latter will be expected to be acquainted with the special uses of the materials they handle, and this knowledge is, of course, of considerable practical value. It is the first function of the warehousemen to watch the stocks under their charge, so that a proper relation is maintained between the amount of stores carried and the normal rate of consumption. The whole science of storekeeping lies in regulating stocks so that current needs will be adequately met, with only a reasonable margin of safety.

Broadly speaking, there would appear to be no substantial differences between the various schemes of stores administration as adopted by the four great railway undertakings in this country. In the main, a very efficient functional unit has been evolved. Needless to say, no room exists in the stores department for excessive systematisation or over-elaborate methods.

Purchase and issue of stores

The purchase and issue of materials are dealt with by two distinct branches of the stores organisation, but the one is essentially the corollary of the other, and should be so considered. As agent of the using departments, the stores department will frame its purchases entirely on the basis of their needs, although the materials, for the sake of convenience, may be temporarily housed in the storehouse, and the actual issue made piecemeal over an indefinite period.

The procurement of stores is accomplished either by purchase from outside sources, by manufacture in the railway workshops, by release of usable material from service, or by reclaiming serviceable material from scrap.

As concerns purchases from outside sources, requisitions received in the order office from the various sectional depots are, as far as possible, consolidated, and orders made on different manufacturers. A large amount of material is purchased under contracts, a method which in general has the great advantage of ensuring quicker delivery than is the case where quotations have to be obtained prior to placing an order. Demands will, however, be made from time to time by the using departments for a good deal of material not covered by contract. In any case, the varied character of railway supplies is such that it is next to impossible to bring every item into the contract schedules. In these instances, quotations will be invited, so that competitive prices may be obtained. It is in the best interests of the railway company that the stores purchasing officers should be allowed sufficient freedom in buying to take advantage of prices.

Proper regard must, of course, be paid to such factors as stock already on hand and probable future consumption where, for instance, it is desired to take advantage of market prices, or to buy in advance because of an expected rise in prise. Some classes of material, although outside the contracts, are purchased to definite specifications, and in these cases, provided always that conditions as to delivery can be complied with, the lowest quotation will be accepted.

An essential thing in connection with issues is to insist that in all cases where material is issued a requisition, duly signed by an authorised officer, is handed to the warehousemen requesting him to hand over certain stores. Such stores will be « checked out » by the issuer, and the shop operative may be expected to see that his requisition has been correctly executed. A strict account must, of course, be kept of all materials taken into the storehouse. On the other hand, if for any reason material were taken away from the storehouse without a

covering requisition being handed over, not only are the storehouse stock records vitiated, but the materials are not charged to the job on which they are used, and wrong costings will result. These points emphasise the need for careful supervision and proper enforcement of regulations.

One other matter in connection with railway stores practice, which affects both the purchase and issue of materials, is the standardising of all items of stores stock. To this end, standard stock lists are drawn up for each of the section storehouses. The lists are kept up to date by eliminating therefrom all articles that have become obsolete, and new articles are given a place in the lists provided that the demand for them is likely to be a regular one. The adoption of this plan in conjunction with the records of all storehouse transactions that are maintained makes it possible to earmark all materials received and issued, and to keep tally of them from the time they come into the storehouse until the moment they go out again. In connection with the purchase of materials, the standard stock lists will be the basis on which the contract schedules are framed. As to issues, to ensure that the stores withdrawn are of the correct variety, it is an accepted rule that requisitions should be made out so that the description of the material (except where this is non-standard, and has to be specially obtained) conforms to the heading on the standard lists.

Control of stocks.

What are the fundamental principles of stock control? One would place first the need for organising to look sufficiently into the future, and to so arrange deliveries that there is always a sufficiency of materials to carry any given plan to conclusion. The maintenance of proper stock records is an important step in this direction, for such records provide a datum line for estimates of future requirements in respect of any class of material. An accurate record of previous performance is probably the safest guide to future accomplishment, but it would be idle to claim that stocks can be controlled effectively, and shortages and surpluses eliminated, without the definite guidance and co-operation of the using departments.

With regard to supplies required for various kinds of maintenance work undertaken in the shops, some regularity of demand exists, and careful forecasts based on past consumption will do much to ensure that stocks are kept at the proper level. Broadly speaking, this applies also in the case of materials supplied to out-station depots. As concerns new constructional work, however, it is obvious that the stores department should be furnished, not only with accurate, but early information.

In the case of a railway stores department, the chief requirements of the system of accounting (stated broadly) will be the maintenance of reliable records — both financial and statistical — of the purchase and issue of materials. This information must be framed in such a form that the position of the stocks is always readily ascertainable. Additionally, a tally will need to be kept of the various expenses incurred by the department.

The actual construction of the financial records proceeds upon conventional lines. Both personal and impersonal accounts are maintained (the former being built up on the bought invoices, credit notes, etc., and the latter on « first entry » data relating to administration expenses). The usual arithmetical check on the correctness of the work is obtained by double entry postings. In connection with purchases, it is extremely important that prompt certification of the quantity and quality of the goods should be given by the storekeeper concerned, so that invoices can

be « released » for payment in time to secure the customary cash discounts.

With regard to the statistical stock records, these represent a distinct branch of the system of stores accounting. A separate account is kept for each class of material, and in the maintenance of these stock records, loose-leaf sheets are employed. The sheets are grouped into convenient sections, which are held together by a suitable locking arrangement. One great advantage of the loose-leaf system is that it readily lends itself to a division of the work of posting the sheets. As already said, the shop requisitions for materials (which are priced out by the stock sheet clerks from an authorised schedule) form part of the data necessary to the compilation of the various process and other cost accounts.

There remain the expenses incurred by the stores department itself in connection with the purchasing, handling, and storing of material. Apart from its domestic significance, this expenditure has to be accounted for in the financial books of the railway company. Although, from an accounting standpoint, the stores department is treated very largely as a separate operative department, the actual expenses of administration are customarily distributed to the primary expense accounts, such as maintenance and renewal of locomotives, and so on, in proportion to the material charged to these accounts. Stores expenses, as such, cannot therefore be identified in the operating expense statements.

Storage problems.

The work of « delivering the goods, » with which the stores department is entrusted, is governed by so many factors that it would be foolish to claim that it is capable of reduction to the terms of an exact science. Changes in equipment standards, changes in shop programmes, unavoidable manufacturing delays, inadequate storehouse accommodation — all these things are encountered. Storage problems are of the practical variety, to be solved as far as possible by the man on the spot. It is desirable, of course, that storehouse accommodation should be designed at the outset on generous lines, due regard being paid to such factors as shop output, character of stocks carried, and so on.

Storage conditions are, however, never such that cleanliness and good order are wholly unattainable. Racks employed for the storage of materials are usually of the open kind, that is, without backs, and so do not harbour the dust. They will also be of standard design, and can, therefore, be adapted for use wherever required. They are, moreover, capable of very easy dismantlement. In arranging the racks throughout the storehouse the « buttress » formation is usually adopted, each section being separated by a few feet, and in the « bays » so formed the stock is readily accessible. The racks should bear legibly written or printed labels, setting out in each case the heading and standard number given in the warehouse stock list. Bins or stacks of material should be similarly labelled, and in the case of iron castings and other supplies stored in the open, a metal tab forms a convenient means of identification.

With regard to the precise method to be followed in storing different classes of material, this is deserving of some study, for sometimes considerable economies in space, or greater ease in handling, is effected by the exercise of a little ingenuity. For example, chain is frequently stored by wrapping it round a four-leg pyramid rack, which will hold it in a neat pile. Springs stored out of doors will be piled on island platforms, with the leaves turned so as to shed water. So stored, the springs are very easily removed from the stack. Casks of oil will be kept in specially-constructed sloping racks, the casks being withdrawn as required from the lower end

of the rack. Where the oil house is actually joined to the stores building, there should be a fire door between the two for protection. An even better plan is for the oil house to be detached from the main building — say, several yards off. It is desirable in the case of rubber and numerous other commodities that they should be protected carefully from exposure or damp. Such articles are usually stored in a walled-off section of the storehouse, the temperature in the section being kept at a slightly higher level than in the rest of the building.

The question of the proper care of outside material — iron castings, in particular — raises what is apparently a highly controversial issue. Our American friends make a great show of fighting « Old Man Rust, » and one gathers that it is a fairly general rule to paint or otherwise treat materials in outside storage. Some railways use paint, and others a patented non-rusting preparation, while still others use petrolatum, with renewal coatings as often as necessary. As an indication of the importance attached to the treatment of outside material, it may be mentioned that at the stores depots of some of the American railways electric cranes have been specially installed for the purpose of dipping small castings before putting them into storage. In Germany, the author recently observed, in the vicinity of a railway stores depot large stocks of « Eisengusswaren » (foundry goods), containing probably some thousands of castings, all of which had been carefully treated with a coloured solution resembling thinned-down paint.

By contrast, the attitude taken up in this country seems to be that such measures are largely unnecessary. The British storekeeper's contention is however, that a regular demand exists for standard types of castings, and it is his business to meet this demand, but at the same time to see that his stocks are not excessive. Consequently, if he does his job in an efficient manner the castings in question will not be standing in stock for a sufficient length of time to warrant treatment with anti-rust preparations. On the other hand, if stocks of castings have accumulated as a result of unexpected changes of practice on the part of the using departments, then there are no grounds for spending time and money in taking more than ordinary care of obsolete castings which are destined ultimately to find their way back to the foundry to be re-cast.

It still appears to be considered by the operating organisations that the stores department has no special claim to be represented in their inner councils, even when the discussions concern the supply of materials. When there are recognised channels through which the stores department can and does obtain information, it is seriously suggested that a representative should be present at all departmental conferences. The first-hand and early knowledge so acquired — whether it be in connection with a new constructional programme or any other matter affecting supplies — would enormously assist the stores department in the better regulation of stocks, with corresponding benefit to the using departments themselves.

It is also the function of the stores department to deal with scrap material. Strictly speaking, the proceeds of the sale of scrap material cannot be regarded as profit, but must be set-off against the enormous loss through depreciation — whether it be wear and tear or obsolescence — of the various assets that go to make up the « stock-in-trade » of the railway. As in the case of materials purchased, the system of competitive tenders is followed, and contracts are usually made for short periods — say three months. It should be said here that obsolescence is a factor that is not lost sight of in connection with the stocks of materials carried in the various storehouses. Incidentally, the periodical stocktaking provides an opportunity

for a review of those items which have been rendered obsolete by changes in practice.

With regard to the stores system itself, an argument commonly advanced from the « consuming » standpoint is that it is inelastic, and incapable of functioning smoothly under any other than static conditions. The answer is that the stores system is the product of many year's experience under varying conditions, and that its policy must of necessity be to maintain stocks at a sufficient level to meet ordinary eventualities. It can and frequently does deal with exceptional demands entailed by deviations from or additions to programmes of work. If sufficient notice is given, the provision of adequate supplies presents in general no real difficulty and in this regard the stores are entirely in the hands of the using departments.

As a means of testing to some extent the standard of achievement attained by the railway stores department in this country, one may usefully contrast it with the purchasing department of an American railroad. It is recognised in that country that the purchasing department has enormous possibilities of careful or of careless administration, and on the larger railways the man at its head is a vice-president of the road. Although the administrative scheme is not everywhere the same, as a general rule the « director of purchases and supplies » will have under him two principal officers, the general purchasing agent and the general storekeeper. The general purchasing agent buys all the supplies of the road, usually being given a free hand up to a specified maximum cost limit. The general storekeeper controls the operative side of the organisation, that is to say, the storage and distribution of supplies, and exercises a general surveillance over the various sectional storekeepers and the stores labour force.

Plenty of evidence is available to show that an excellent service of supply is provided. For one thing, it is perfectly obvious that the operating organisations would not have reached their present level of efficiency without a proper system of provisionment. In characteristic fashion, the fullest possible use is made of labour saving devices, a direction in which we ourselves are decidedly backward.

MISCELLANEOUS INFORMATION

[625 .143.3 (.73)]

1. — Rail wear cut 80 per cent by Norfolk and Western flange oiler.

Figs. 1 to 5, pp. 704 and 706.

(*Railway Engineering and Maintenance.*)

The problem of rail wear on curves has been given much study on the Norfolk and Western with a resultant increase of about 400 % in the life of rails in these locations. While this problem has existed to a more or less extent at every curve, it has been particularly acute on the Radford division of the Norfolk and Western which crosses the Allegheny mountains between Roanoke and Bluefield, Va. Here, through a distance of 100 miles, the curvature ranges from 3° to 12°, and on the two mountain grades of this line where 65 % of the track is on curves, the curves vary from 6° to 12°. The maximum super-elevation on the curves is 5 inches, and the maximum grades on the east-bound track, upon which an average of 70 000 tons is moved daily, are 1.3 % ascending and 1.6 % descending.

Rail wear on curves was severe.

With these conditions prevailing, rail wear on the curves within this territory has been particularly severe. This is evidenced by the fact that the average life of 130-lb. rails on the high sides of 10° to 12° curves has been only 2 to 3 years. On the low sides of curves the life of the rails has been usually about 50 % longer than on the high sides.

Confronted with this situation the Norfolk and Western began experimenting about two years ago with the application of oil to the inside of the heads of the rails on the high sides of curves. At first the oil was applied to the rails by section men with short stub paint brushes, at intervals of about 12 inches over a distance of from 10 to 12 rail lengths on two curves in opposite directions, care being taken to keep the oil from the tops of the heads where it would interfere with traction. With the rails so oiled, it was found that the oil was picked up by both right and left wheel flanges of passing trains and was distributed by them wherever the flanges were thrown against the rails within distances ranging from 3 to 12 miles. Thus, one application at a point where the oil was sure to be picked up by the wheel flanges, was found sufficient to oil adequately the flange-wearing surfaces of the rails on a number of succeeding curves. The tests made were so successful in minimizing the amount of rail wear that the practice of oiling the rails, as outlined, was extended to all other portions of the Norfolk and Western where the curvature and resultant rail wear justified its use.

Mechanical methods of applying oil were devised.

While the practice had been proved sound, it was apparent that the hand method of applying the oil was slow and costly. In the first place, application of the oil with the brush was in most instances wasteful in the amount of oil used, and in the second place it required the employment of three men on eight-hour shifts at each lubricating point in order that the oil could be applied immediately following the passage of each tonnage train throughout the day and night, these men being assigned specially to this work, except where it was possible to locate the oiling points appropriately and turn the work over to regularly assigned bluff and tunnel watchmen. Where special men were assigned, which was the usual case, approximately 90 % of the

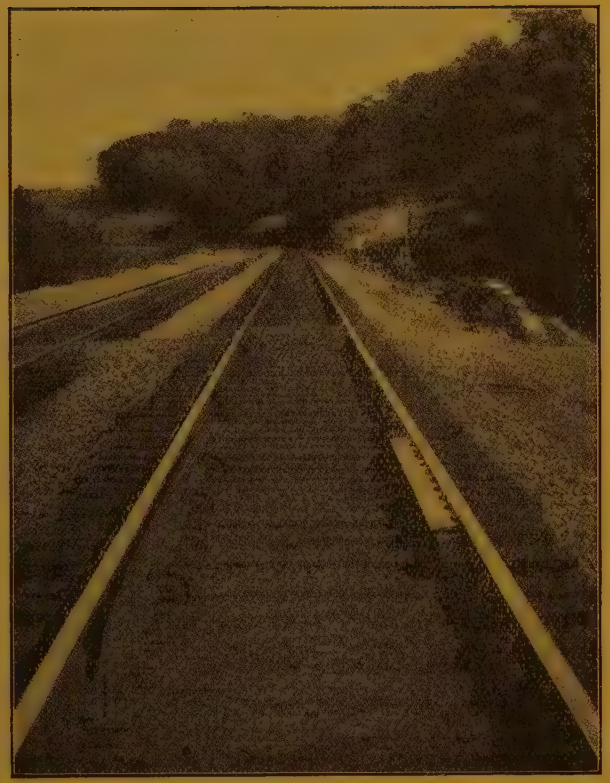

Fig. 1. — Flange oiler installed in main track.

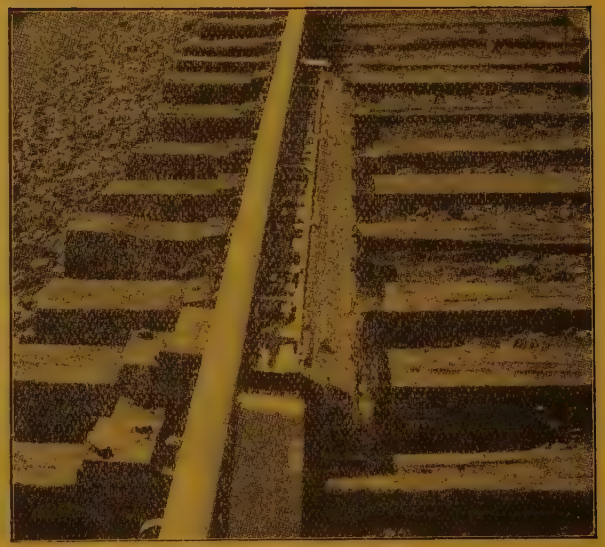

Fig. 2. — Flange oiler with cover removed.

Fig. 3. — View of pawl and ratchet.

total cost of oiling the rails was for labor with only about 10 % for oil and the brushes used in applying it.

This being the situation, the next logical step in the development of the process was to find a more practical and economical means of applying the oil exactly where it was needed, and to this end some of the section men assigned to oiling the rails by hand, devised contrivances, with the encouragement of the company, which could be pushed by hand so that the rails were oiled as fast as the operator could walk. One of the most successful of these consisted of a simple metal container mounted on a low carriage with double-flanged rollers, which could be pushed along the rails by means of handles similar to those found on the common plow. In this arrangement, after heating the oiling mixture, the oil flows through a short pipe, equipped with a suitable regulating valve, to the top of a brush which distributes it along the gage side of the rail heads.

While these methods were an improvement over applying the oil by hand and effected some saving in oil, the labor cost still remained high. This brought about the general feeling that the solution of the problem lay in devising a means of applying the oil directly to the wheel flanges instead of to the rail. Acting on this principle, a number of the supervisory officers of the Norfolk and Western continued their study of the subject along this line, which led to the development of two or three automatic flange-oiling machines of considerable merit. All of these are designed to be installed within the track, close to the gage side of the rail where passing wheel flanges can pick up a correct amount of oil and carry it to the curves ahead.

One of these machines is a metal box-like oil container which is rigidly bolted and spiked to the gage side of the rail. This box has a hinged section along the top which is depressed under the action of the wheel flanges of passing trains, opening the top of the oil container and acting against a lever in the bottom of the box, which in turn raises the oil sufficiently to coat a rubber wiper which comes in contact with the side of the rail head and the wheel flanges.

The Derrick rail and flange lubricator.

While this machine and a number of others were tried out with considerable success, and their further development encouraged, the most practical and successful machine devised was the one designed by J. R. Derrick, assistant superintendent of the Radford division. This machine consists of a covered metal box or trough 10 ft. 3 in. long by 5 inches wide and 4 inches high, which is bolted to the web of the rail on the gage side. Within this box is a series of 10 leather discs, 5 inches in diameter equally spaced throughout the box and mounted in a vertical position on suitable cross shafts. In operation, these discs revolve under the influence of passing trains and carry oil from the reservoir up to the gage side of the wheel flanges with which they come in contact.

In accomplishing this, all of the disc shafts are fitted with fixed sprockets which are driven in synchronism by means of a continuous roller chain operating alternately over the sprockets and under idler shafts spaced between them. Driving of the chain is effected by means of a ratchet and pawl mechanism on a drive shaft at one end of the box through which the relative vertical motion between the rail and the ties at this point is transformed into rotary motion of the ratchet and shaft. In this arrangement the drive shaft extends through the oil box and the web of the rail, and the end is fitted with a fixed ratchet wheel. Operation of this wheel is by means of two pawls, supported by a steel bracket which is fastened securely to two adjacent ties outside of the rail by lag screws. These pawls, which are hung in the plane of the wheel and held against it by means of springs, rack the wheel in a clock-wise direction by means of the relative motion between the rail and the ties under moving loads, sufficient motion of this character being provided by drawing the spikes slightly from the two supporting ties. In this manner, rotary motion is transmitted to the drive shaft and thence, by means of the

Fig. 4. — Flange oiler complete.

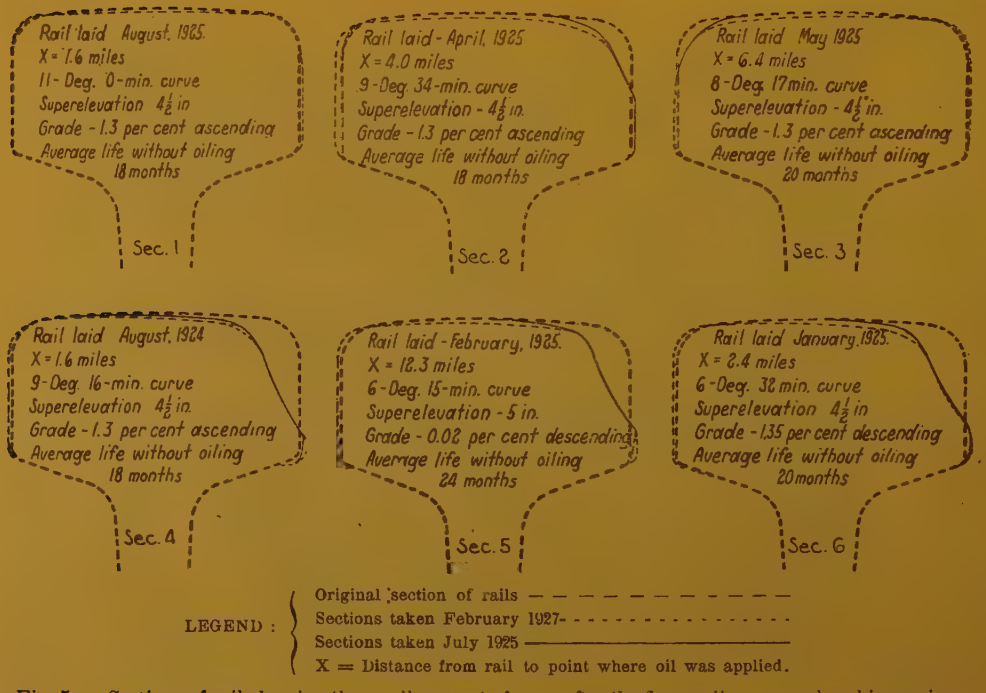

Fig. 5. — Sections of rail showing the small amount of wear after the flange oilers were placed in service.

chain and sprockets, to each of the oiling discs.

In actual service, this machine is installed at the center or quarter point of a rail, preferably about 100 feet ahead of a curve, and in all cases accompanied by the installation of a guard rail immediately opposite, the purpose of which is to prevent the crushing of the oiling disc between the flanges of passing wheels and the head of the high rail. This guard rail also prevents lateral motion of engine and car wheels and retains their flanges in the desired contact with the oiling discs.

The oil used in this device is a heavy, sticky and viscous oil, now obtainable from the oil companies in the proper consistencies for summer and winter use. While the consumption of the machine is dependent directly upon the amount of traffic over it, the usual consumption of those machines which have been in service ranges from about one-half gallon to one gallon per day.

The Derrick rail and flange lubricator is now being manufactured and sold by the Maintenance Equipment Company, Chicago.

Oiling effects large economies.

The advantages which have been obtained on the Norfolk and Western through flange and rail oiling by the various methods described, have been very definite, the most important of these being the striking reduction in the wear of the rails on curves and the corresponding increase in the service life of these rails, which in most cases has been extended approximately four times. That such unusual results have been and are being obtained in this respect, is evidenced by the accompanying sketches of 130-lb. P. S. rail sections made from actual measurements taken in the track.

These sketches show the original sections of the rails as laid new; the sections of these rails after from 3 to 11 months service without oiling, and also, sections of these same rails about 19 months after oiling was begun. In the last five of these instances, which are typical of the results being obtained on the Norfolk and Western, is shown the excessive rail wear on the gage side of the rail heads in the few months previous to oiling, and the almost negligible increase in the amount of this wear in the 19 months immediately following the oiling. In rail section No. 1, which is that of rail laid shortly after oiling was begun, is indicated also the almost inappreciable amount of flange wear on new rails which have been oiled, after 18 months of service, and this, in this case, in spite of the fact that the rail was located on an 11° curve.

Striking also, as indicated by the notes accompanying each rail section, is the apparent effectiveness with which the oil is carried to great distances from the point of application, this distance, in the case of section 5, being over 12 miles. Irrespective of this distance from the point of application, the oil was applied so thoroughly that the excessive flange wear which occurred in the 4 months previous to oiling, was completely stopped in the 19 months during which oil was applied. Evidence that the oil is properly applied and does not reach the top surface of the rail heads, is seen in each case by the fact that whereas side wear was almost stopped, wear on the top of the rail heads continued at the normal rate.

While the accompanying sketches are conclusive as to the actual results being accomplished in the way of lengthening the life of rails on curves by oiling, and indicate indirectly the large savings being made in the cost of rail renewals, to this, in order to get the total savings effected, should be added the labor cost formerly required for the frequent renewal of rails on curves; the labor cost of the frequent regaging of the tracks on curves formerly required due to rail wear; the former loss through damage to ties caused by frequent respiking to gage; the saving through the longer service life given to engine and car wheels, and the less easily computed but no less real saving that is being effected through the acceleration of train movements made possible by decreased friction on curves.

We are indebted for the information contained in this article to Floyd E. Chabot, assistant editor of the Norfolk & Western magazine.

[62. (01 & 669]

2. — « Creep » stresses.

(*Engineering.*)

In a highly instructive and suggestive presidential address, delivered some few years ago, to the Institution of Mechanical Engineers, Professor W. C. Unwin pointed out that a purely empirical factor was necessarily involved in any satisfactory method of fixing permissible working stresses. Thus, boilers have been commonly designed for a factor of safety of 5, the corresponding figure for guns being about 2. A steel spring may occasionally be loaded up to about three-quarters of the ultimate strength of the material, whilst in masonry work factors of safety of twenty or more are far from uncommon. In this connection, neither the mathematician nor the physicist has been able to assist the engineer, who, when met with novel problems, has quite commonly had no alternative save a resort to the good old traditional rule of « guessing half and doubling it ». He has, moreover, had to make his guess burdened by the consciousness that if his pioneering venture succeeds, he will have to meet the competition of a host of mere copyists, whilst a mistake may involve him in ruinous pecuniary losses. No other professional man works under any corresponding handicap. It is a long-standing gibe that the doctor's mistakes are forthwith shovelled underground, whilst blunders of the barrister are paid for by his clients. The clients of the manufacturing engineer, however, are less accommodating, and commonly insist that not only shall the engineer make good his errors of judgment, but shall also be responsible for any consequential damages resulting therefrom. The chemist or physicist, again, is mainly concerned with what we ought to think, but the engineer is almost invariably called upon to translate thought into action, and may well be excused for the caution he commonly displays in transcending experience. Large extrapolations involve serious risks, since it is notorious in such cases that after provision has been made for every conceivable contingency, the change of scale may bring to light others previously entirely unsuspected and unforeseen.

One of the most serious problems with which the mechanical engineer is to-day confronted is that of dealing with « creep ». For years past, the engineer has been able to rely on certain standard tests of the materials he employs. Experience has proved that certain qualities of steel give satisfactory service in certain conditions, and the tests in question, though often derided as unscientific, do ensure that the material supplied is of the quality desired. In most cases, working stresses have been fixed as some definite fraction of the ultimate stress as determined by the tests in question, and recent experiments have shown that in adopting this procedure, the engineer was really building better than he knew, and that even under alternating stresses, the actual strength of most materials is more closely correlated with the ultimate strength than it is with the elastic limit.

It was known, of course, that the ultimate strength was to some extent a function of the rate of testing, but at ordinary temperatures this time effect was of little significance. A serious situation arose, however, when it was discovered that at the temperatures now met with in power-station practice, the ultimate strength of many otherwise excellent steels falls off very rapidly as the duration of the test is prolonged.

It has been usual to assume that there was a limit to this « creep », and that if the stress were fixed sufficiently low the phenomenon would not arise. This view is challenged in a highly interesting and very suggestive paper read on the 21 April 1927, before the North-Western branch of the Institution of Mechanical Engineers, by Mr. R. W. Bailey, of the Metropolitan-Vickers Electrical Company. By changing the method hitherto adopted of plotting the results of observations, Mr. Bailey is led to the conclusion that « creep » always exists, but that at ordinary temperatures the rate is too small to be detected. On this view, no body is per-

fectly elastic. That this is the case was asserted many years ago, by Professor Bouasse, as the result of experiments on wires.

In this connection it is, however, necessary to note that the term « perfectly elastic » is used with two different significations. Probably no body follows Hooke's law with perfect exactitude, but there does seem satisfactory evidence that elasticity of form may be sensibly perfect. The balance spring of a chronometer which works under an alternating stress having a total range of about 18 tons or 19 tons per square inch, maintains an unvarying rate for years. This fact seems hardly compatible with the idea that « creep » like the « poor » is always with us. Undoubtedly there are conditions in which « creep » occurs under extraordinarily small stresses.

It has been stated that wax seals found in Egyptian tombs, which were no doubt sharp impressions originally, have in the course of forty centuries sunk into shapeless pools under the stress of their own weight. Again, Mr. Ch. Guillaume, of the International Bureau of Weights and Measures, has pointed out that the nickel-iron alloy, which is held to constitute that part of the earth known as the barysphere, must be regarded as a liquid for long-continued stresses, but as a solid for transient ones. It thus has just the properties which Mr. Bailey attributes to our ordinary structural materials. On the other hand, Snowdon is probably some 400 or 500 million years old, and were creep the universal property suggested it would hardly still raise its head nearly 3 600 feet above sea level. The behaviour of metals as tested at normal temperature also seems rather more favourable to the hypothesis of a limiting creep stress than it is to the somewhat revolutionary alternative suggested by Mr. Bailey. As already noted, however, the engineer has to embody his philosophical speculations into concrete machines and structures, and Mr. Bailey brings forward evidence which seems to indicate that this limiting creep stress is much smaller than is commonly recognised, and the question arises as to how this somewhat serious situation is to be met. If working stresses are to be kept below this limit it will be necessary either to resort to the exclusive use of certain special steels where high temperatures have to be dealt with, or to increase scantlings to such an extent as to involve not only extravagant costs, but also to run the risk of serious temperature strains. Mr. Bailey proposes, therefore, the bold alternative of fixing the stresses at such a limit that though creep occurs it will take place so slowly as to involve no material deformations during the lifetime of the high-temperature plant. He assumes that the rate of creep diminishes exponentially as the stress, and proposes to proportion tubes and other elements on the assumption that plastic flow occurs. Whilst in details, his analysis of plastic strain seems to stand in need of some revision, his final results appear to be qualitatively correct. He shows, for example, that if the material be plastic, in the case of a tube exposed to internal pressure the stress is highest at the external surface. The reverse is the case when the stresses are calculated on the elastic theory in which stress is always exactly proportional to strain. In this connection it is of interest to recall the experiments of Professor Bridgman of Harvard, who, in the course of experiments with extremely high pressures, found that thick tubes never failed in the manner suggested by the orthodox theory, but that it was always the external surface which first gave way.

It is of interest to note in this connection that the late Professor John Perry, in a letter published in our issue of 12 March 1915, on page 306, proposed taking advantage of the plastic properties of steel to simplify and cheapen the construction of ordnance. He had, moreover, worked out a more or less rational method of determining the dimensions required, which he explained in the letter cited. Again, it has long been recognised that the strength of solid beams is far greater than can be accounted for on the orthodox theory. It was, we believe, Considère who first pointed out, some forty years or more ago, that the explanation of the high resistance of solid beams was to be found in the distribution of the stress being entirely changed before rupture by the plastic flow of the material. It

has generally been held, however, that there is a definite limit to the creep, and that neither Professor Perry's gun nor the solid beam would continue to give way indefinitely, and we see no sufficient reason for questioning this conclusion. The novel point raised by Mr. Bailey is, however, that it is possible to provide for the case in which creep is continuous and that therefore it may be legitimate in certain cases to adopt working stresses higher than would be permissible, were these fixed on the hypothesis of a limiting creep stress. His bold and ingenious suggestion will no doubt receive careful consideration by those responsible for the design and construction of high temperature plant.

[625 .251]

3. — « Chamon » system automatic variable power brake for goods trains.

Figs. 6 to 8, pp. 711 and 712.

The application of continuous brakes to goods trains raises many different problems.

The length of the trains and the type of screw coupling still in general use in Europe make it necessary to improve the action of the brake so as to make it more nearly simultaneous in order to prevent the train bunching up and the dangerous reactions which result therefrom.

On long severe gradients it is generally agreed that the brake required must have a graduated release so that the braking power can be modified as desired without having to release it fully. This is one of the main advantages of the vacuum brake. With compressed air brakes attempts have been made to solve the problem by improving the distributor exhaust.

Another problem to be solved is that of braking the load. The question arises in the case of goods trains because, unlike passenger trains, the weight of the loaded vehicle is much greater than the empty weight. Inventors have tried to solve the problem in two different ways. Some have altered parts of the brake itself, as by making the distributor bring into action a second cylinder (double chamber cylinder in the Kunze-Knorr, single chamber in the Westinghouse). Other inventors have endeavoured to vary the braking effort by the action of the spring borne weight on the brake rigging without touching the compressed air parts.

The « Chamon » system can be included in the second group.

As a trial it was fitted to four 30-t. bogie wagons, taring 15.2 t. belonging to the Company operating the Tunisian Railways.

Mr. L. Poulain, Engineer, Corps des Mines, Assistant to the Director controlling the Tunisian Railways, has given a description of the gear and of the trials carried out with it in the *Revue générale des chemins de fer* (January 1927). The wagons were fitted with the Clayton vacuum brake using two 15-inch (380 mm.) cylinders each acting on one bogie with one brake block per wheel.

In the first tests, the two cylinders were connected so as to make them both act on the rigging of the bogie fitted with the « Chamon » gear.

Figures 6 and 7 shew the arrangement as given in the patent specification and as used for the first tests (one block per wheel).

The lower part of the bogie pivot is made up of two parts 1 and 2, the first being fastened to the bolster of the bogie, the second able to move upwards with respect to the former on which it normally rests. A cylindrical guide 3 transmits the horizontal forces from one to the other of parts 1 and 2 and two flat guides 4 prevent any relative angular movement of the same parts.

The centre pivot pin carries a pin 5 at its lower end, with a lever 6, coupled by rods 7, to two cranked levers 8 (these latter are carried by the pins 9 attached to the bogie bolster) connected at their ends 10 to the brake rigging which does not differ from the usual

brake gear, whether of the single block (fig. 7) or two blocks (fig. 8) per wheel type.

Springs suitably arranged keep the gear in tension and automatically take up any play in the joints.

A spring device 11 with a certain initial tension is inserted between the head of the centre pin 5 and the part 1 secured to the bogie bolster. In addition, this pin carries a washer 12 (fig. 6) which forms a collar and comes into contact with the lower side of part 2.

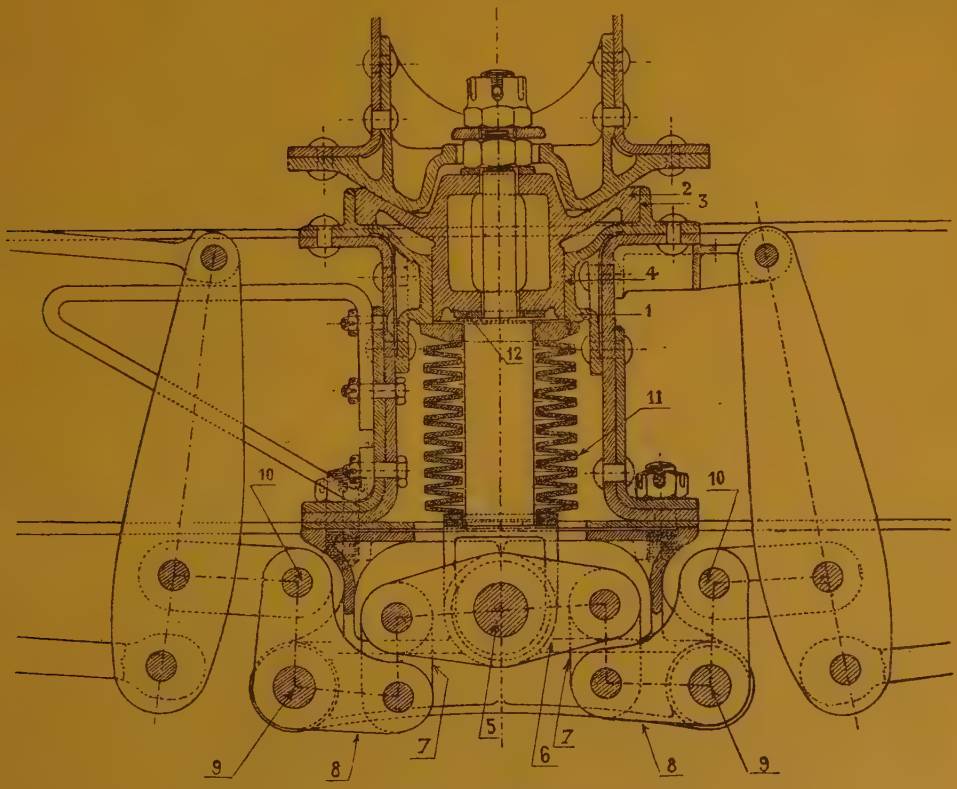

Fig. 6. — Sectional elevation at bogie pivot.

When the brake cylinder comes into action, it first of all brings the blocks up to the wheels.

When this contact has been made, the brake gear beyond lever 6 to the right *i. e.* towards the « fixed point », cannot move any more so that, as the piston continues its stroke, the rotation of lever 6, which so far has been about its centre pin, can now only take place about its extreme right-hand pin.

It will be readily seen that in consequence it exercises at 5 on the pivot pin a vertical thrust transmitted partly through the spring 11 which compresses, and partly to the part 2 which, with the body and its load, moves upwards following the motion of the piston and stopping with it, either when it reaches the end of the cylinder or any other special stop provided for the purpose.

As the spring 11 is designed to give at half stroke a resistance equal to the weight of the bogie and wheels, the total thrust at 5 equals

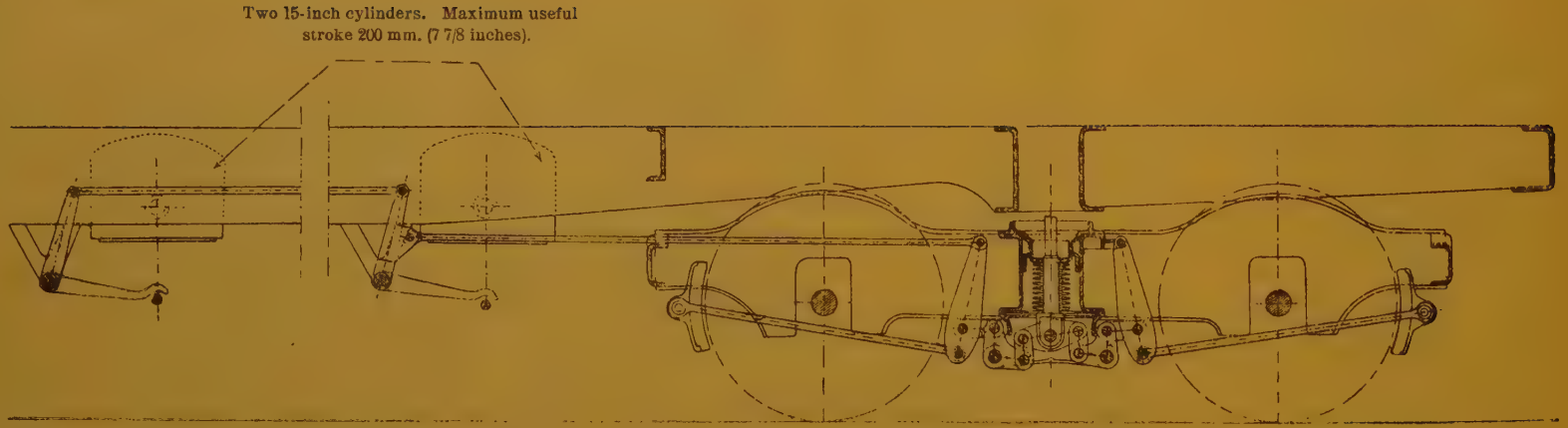
Two 15-inch cylinders. Maximum useful
stroke 200 mm. (7 7/8 inches).

Fig. 7.

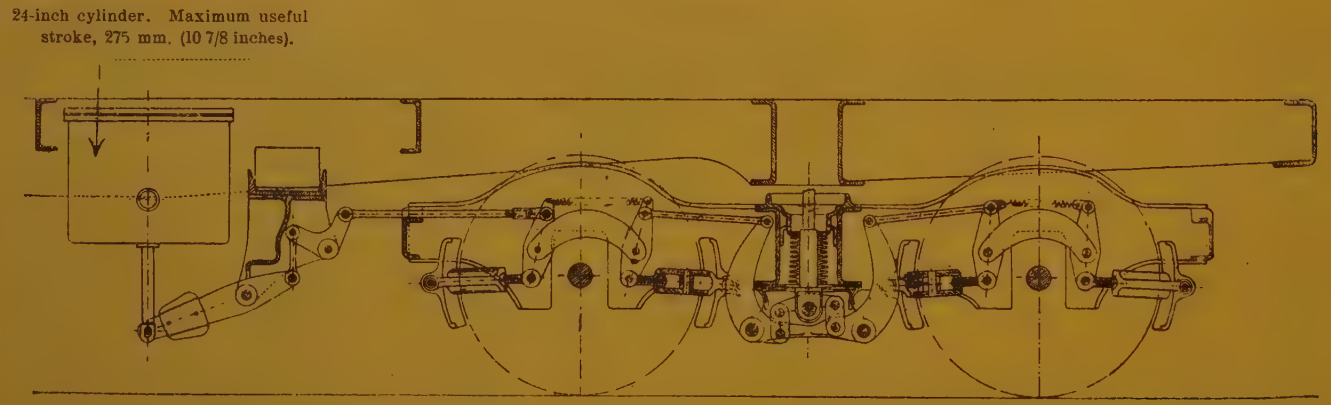
24-inch cylinder. Maximum useful
stroke, 275 mm. (10 7/8 inches).

Fig. 8.

half the total weight of the vehicle (bogie and axles + 1/2 body + 1/2 load).

In addition, this thrust is obviously proportional as is every force transmitted by any part of the brake gear, to the pressure exerted by the blocks on the wheels, with the result that this pressure is also, no matter to what extent the wagon is loaded, proportional to the weight of the vehicle on the rails.

This result pre-supposes that under all circumstances the piston makes its full stroke, or, in other words, that the effort exerted by the fluid considered (compressed or atmospheric air) on the said piston is always at least equal to that required to raise the body when fully loaded, any excess being absorbed by the reaction exercised at the end of the stroke by the stop (end of cylinder or other method).

If, however, this condition is not realised and if, as for example owing to insufficient pressure in the cylinder, the stroke of the piston was only enough to bring the blocks up to the wheels, no great inconvenience would result : in this event, the brake would, in effect, act like the ordinary brake, *i. e.*, the braking effort would be a function of the pressure in the cylinder and no longer of the total weight of the vehicle.

It should furthermore be noted that the value of this pressure, whilst always less than that required to lift the body, can be very much greater than that which could be allowed with the ordinary brake gear when braking empty weights.

This was found to be so during the first set of tests when the arrangement of figure 7 was used, and owing to the two 15-inch cylinders being insufficiently powerful was found unable to raise the body, but did none the less give sufficient brake power to stop the trains in a distance little greater than obtained with the ordinary brake gear.

After the first series of tests which gave very interesting results, but which could not be conclusive, owing to the rough and ready way in which the stock had been fitted, the layout shewn in figure 8 was adopted.

The principal differences as compared with the first are :

1. A single 24-inch (610 mm.) cylinder with a useful stroke of 10 7/8 inches (275 mm.) was used in place of two 15-inch (380 mm.) cylinders with a useful stroke of 7 7/8 inches (200 mm.) and the available power was thereby increased in the ratio

$$\frac{24^2 \times 275}{2 \times 15^2 \times 200} = 1.76$$

2. By using brake gear with two blocks per wheel, so as to avoid the displacement of the wheels caused by single blocks, an important reduction in the unit pressure was obtained and, consequently, in heating which lessens the efficiency of the brake.

3. By strengthening the less rigid parts of the gear to reduce the loss of piston stroke.

These improvements once made, a new series of tests were carried out in May-June 1924, and repeated in February 1926, after the wagons had been in ordinary use for eighteen months.

The details of the tests can be found in the article from which these notes have been taken. They have enabled many very interesting observations to be made.

The conclusion which can be drawn is that, with the « Chamon » system, the braking of the load of a train can be assured automatically under normal safety conditions with the full brake equipment, supposing high capacity wagons with an average tare of half the load, *using only one third as many fully fitted vehicles as with the ordinary brake.*

It should therefore be possible when braking the loaded weight to considerably reduce the cost of fitting continuous brakes to goods trains and this appears to have been the Inventor's first object. In the instances where the ordinary brake based on the tare weights is insufficient, such as on heavy gradients, the arrangement will give the desired result when all the wheels are braked.

E. M.

[621 .132.3 (.71) & 621 .132.5 (.71)]

4. — Locomotive boilers with nickel steel shells. Alloy steels in the frames and in the running gear.

Fig. 9, p. 716.

(From *The Railway Mechanical Engineer.*)

Pacific and *Mikado* type locomotives of 42 600 lb. and 56 300 lb. tractive force, respectively, have been the standard heavy passenger and general freight service locomotives on the Canadian Pacific for the past eight years. These locomotives were designed in 1919 by the mechanical staff of the Canadian Pacific as the largest locomotives of their respective types that could be generally used for main line traffic. There was nothing unusual about these locomotives; they were well proportioned, power operating at 200 lb. boiler pressure. When the question of additional power was being considered in 1926, it was decided that in general these two classes of locomotives should be perpetuated with the exception that such improvements in capacity and efficiency would be made as was possible without increasing the weight beyond a rather narrow range. What was accomplished in this respect is illustrated in the following table which gives a comparison of the principal weights, dimensions and proportions of the earlier locomotives and the new designs :

Comparison of principal proportions of the former « Pacific » and « Mikado » designs with those of the new locomotives.

—	*Pacifics.*		*Mikados.*	
	New.	Former.	New.	Former.
Tractive force, lb.	45 000	42 600	57 100	56 300
Cylinder horsepower (Cole).	2 379	2 252	2 379	2 342
Cylinders, diameter and stroke	23 × 30	25 × 30	23 × 32	25 1/2 × 32
Diameter of drivers, inches	75	75	63	63
Weight on drivers, lb.	184 300	179 300	244 600	240 100
Total weight of engine, lb.	306 500	300 500	335 200	321 800
Boiler pressure, lb. per square inch	250	200	250	200
Grate area, square feet	65	65	70.3	70.2
Total evap. heating surface, square feet.	3 272	3 530	3 436	3 562
Total superheating surface, square feet.	864	803	970	973
Comb. evap. and superheating, square feet.	4 136	4 333	4 406	4 535
Weight on drivers ÷ tractive force.	4.08	4.22	4.2	4.27

Modifications eventually decided on included an increase in boiler pressure of 25 % or up to 250 lb. pressure per square inch, the use of feedwater heaters, the use of front end throttles and the operation of auxiliaries by superheated steam. The application of the Elesco closed type of feedwater heater with a C-F1 class duplex pump, accounted for the increase in weight of 6 000 lb. To increase the boiler pressure 25 % and at the same time to keep within a total locomotive weight increase of 2 % would, on the face of it, appear an impossibility. But in doing this, the Canadian Pacific put into effect a step in locomotive

construction that it has been investigating and considering for a considerable length of time. This was the use of nickel steel boiler plate of 70 000 lb. per square inch, minimum tensile strength, which permitted on the two designs of locomotives under discussion an increase in boiler pressure up to 250 lb. per square inch without any change in the thickness of the barrel course plates. Altogether, 44 locomotives were constructed in 1926, 24 *Pacific* type locomotives being built by the Montreal Locomotive Works, Montreal, Que., and 20 *Mikado* type constructed by the Canadian Locomotive Company, Kingston, Ont. All 44 were delivered during August, September and October, 1926, and they have fully justified the expectations of improved performance and efficiency due to the higher boiler pressure and other improvements in design.

The boiler has been changed very little over the base design for 200 lb. pressure. It is of the radial stay type and beyond the thickening of the wrapper sheet and firebox side sheets and a careful investigation and checking of all details of construction, there are practically no changes made other than the substitution of nickel steel boiler plate for carbon steel in the first, second and third course sheets and welt sheets and the use of steel for longitudinal braces of the boiler.

The nickel steel boiler plate is open hearth basic steel made and rolled by the Lukens Steel Company with the joint inspection and co-operation of the American Locomotive Company, the International Nickel Company and the Canadian Pacific. It was anticipated that the plates would have a somewhat pitted surface typical of nickel steel but the surface conditions were quite equal to carbon steel boiler plate. The physical and chemical requirements for the nickel steel, called for on the railway company's specifications, as compared with carbon steel, are as follows :

	Carbon steel.	*Nickel steel.*
Carbon	Not specified.	0.20 maximum.
Manganese	0.3 to 0.6	0.4 to 0.8
Phosphorus	0.04 maximum.	0.045 maximum.
Sulphur	0.05 maximum.	0.045 maximum.
Nickel	...	2.75 to 3.25
Tensile strength	55 000 to 65 000 lb.	70 000 lb. minimum.
Yield point (minimum in lb. per square inch)	50 % of tensile strength.	50 % of tensile strength.
Elongation in 8 inches (minimum per cent)	1 500 000 ÷ tensile strength.	1 600 000 ÷ tensile strength (with 20 % fixed minimum).
Reduction of area (minimum)	Not specified.	50 %

It will be noted from the specifications that this material will effect a saving of 27 % in the weight of the barrel course sheets, or permit the use of higher pressure without a corresponding weight increase.

This being the first alloy steel produced by the Lukens Steel Company, there was some preliminary work and investigation required before the material was finally produced on a commercial basis, but once started, very uniform material was produced. To illustrate, an analysis was made of the physical properties of 465 determinations of nickel steel boiler plate and an equal number for carbon steel boiler plate on a previous order for locomotives. The average results obtained on the nickel steel were as follows : Tensile strength, 76 700 lb.; yield point, 46 800 lb.; elongation, 26 %, and reduction of area, 53 %. The average tensile strength and yield point for carbon steel boiler plate ran 59 200 lb. and 36 200 lb., respectively, so that the gain in strength based on average results is 29 % on both the ultimate strength and yield point basis.

The maximum variation in the various physical properties above and below the average were found to be almost identical for the nickel steel and for an equal number of carbon steel determinations.

The nickel material is remarkably tough and

ductile and generally speaking, in the transverse bend tests, the heaviest plate can be bent flat on itself without fracture. Specification requirements call for bending of the plate around a pin, the diameter of which is equal to a certain percentage of the plate thickness, this being worked on a sliding scale based on the usual practice for carbon steel. As nickel steel stood this test readily, the tests were usually carried further until the plate would bend flat on itself and the illustration (fig. 1) shows a typical specimen which illustrates the

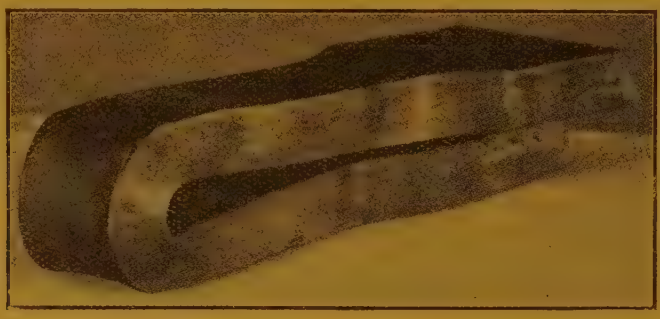

Fig. 9. — Test specimen illustrating the ductility of the nickel used in the boiler construction.

ductility of the material and its ability to withstand the transverse bend tests. From the shop viewpoint, there is little if any difference between nickel and carbon steel.

The frames of the *Mikado* type locomotives are of carbon-vanadium steel and the frames of the *Pacific* type locomotives are of carbon-vanadium steel on half the order and nickel steel on the balance of the locomotives. The Canadian Pacific has been using vanadium steel frames for 15 years and for the past four years has been purchasing alloy frames to very severe specification requirements. Eight test coupons are cast on selected locations on each frame and six coupons are pulled for each individual frame, the remaining two being left on for additional annealing treatment if required. The frames are required to be of reasonably uniform hardness and the range in hardness permitted is specified on the Brinell system. Exceptionally good results have been obtained for a number of years from the use of alloy steels for locomotive frames.

The following shows the average physical results obtained from both the vanadium and nickel steel frames :

		Vanadium steel.	*Nickel steel.*
Average physical properties.	Tensile strength. . . .	87 590 lb. per square inch.	79 472 lb. per square inch.
	Yield point	49 442 lb. per square inch.	48 472 lb. per square inch.
	Elongation.	28.5 °/o	30.4 °/o
	Reduction of area . . .	53.6 °/o	55.8 °/o

A typical analysis of the chemical composition of the two materials is given in the following table :

		Vanadium steel.	*Nickel steel.*
Average chemical composition.	Carbon	0.35 °/o	0.17 °/o
	Manganese.	0.94 °/o	0.8 °/o
	Phosphorus	0.016 °/o	0.014 °/o
	Sulphur	0.029 °/o	0.029 °/o
	Silicon.	0.35 °/o	0.35 °/o
	Vanadium	0.19 °/o	...
	Nickel	...	2.8

There was a particular incentive in increasing the efficiency and capacity of the *Pacific* type locomotives as this class of power handles very heavy trains on severe schedules, at high speeds. More than the usual care was, therefore, paid to the design of the reciprocating parts, not only to reduce the weight, but to use the highest grade of steel obtainable. Alloy steel has been used for main and side rods on both freight and passenger power for a considerable number of years past and this practice was continued with both classes of power, the *Pacific* type locomotives being equipped with carbon-vanadium rods and the freight power with nickel steel rods. This was the Canadian Pacific's first experience with nickel steel rods and good results were obtained. The average physical characteristics for all rods on both classes of locomotives are as follows :

	Carbon-vanadium.	*Nickel.*
Tensile strength	95 004 lb. per square inch.	104 900 lb. per square inch.
Yield point	63 357 lb. per square inch.	66 760 lb. per square inch.
Elongation	27.7 °/₀	25.3 °/₀
Reduction of area	54.24 °/₀	51.8 °/₀

[385 .113 (.438)]

5. — The Polish State Railways in 1925.

(*Bulletin de l'Union internationale des chemins de fer.*)

1. — Length of lines in operation.

The length of *standard gauge* lines was 17 052 km. (10 596 miles) at the 31 December 1925. The average length of these lines in operation during 1925 was 16 847 km. (10 468 miles) : of this length 1 342 km. (834 miles) belonged to private companies, but were State operated : its operating costs are deducted from the traffic receipts and the balance paid to the owning companies.

2. — Traffic returns.

The following table gives the comparative figures for 1924 and 1925 :

—	1925	1924
a) Passenger :		
1. Number of passengers	162 603 691	177 127 558
2. Passenger-kilometres (passenger miles)	6 366 217 848 (3 955 855 809)	6 897 420 655 (4 285 935 879)
3. Receipts (passenger and luggage) (zlotys)	278 566 000	241 045 000
4. Receipts per passenger-kilometre (per passenger-mile) with luggage	0.044 (0.071)	0.035 (0.056)
5. Average journey, in kilometres (miles)	39.2 (24.4)	39.1 (24.3)
b) Freight :		
1. Metric tons (English tons)	58 363 420 (57 441 623)	59 962 763 (59 015 706)
2. Ton-kilometres (English ton-miles)	12 634 444 000 (7 726 825 185)	11 036 908 675 (6 749 823 255)
3. Receipts (zlotys)	543 070 000	476 693 719

—	1925	1924
4. Receipts per ton-kilometre (per English ton-mile) .	0.044 (0.072)	0.043 (0.070)
5. Average haul, in kilometres (miles)	210.9 (131.0)	184.0 (114.3)
6. Number of wagons :		
loaded in the country	3 797 202	3 870 900
received from abroad.	549 050	619 536

The cause of the drop in traffic in 1925 was the economic crisis resulting from the reform of the currency. The increase shewn in the passenger receipts was due to an increase of about 25 % in the passenger tariffs in 1925.

The increase in the number of ton-kilometres in freight traffic, in spite of a reduced tonnage carried, is explained as follows :

Germany having forbidden, as from the 1 July 1925, the importation into its territory of coal from Upper Silesia, the output of the Polish collieries instead of being sent to the nearby frontier had to be sent for exportation to far distant Baltic ports : this marked increase in the distance hauled of the loaded wagons of coal caused an increase in the ton-kilometres and of the average haul per ton.

The notable reduction in the number of wagons from abroad in 1925 was the result of the steps taken by the Government to limit the importation of foreign goods.

COMPARATIVE STATISTICS WITH THE RAILWAYS OF THE STATES BETWEEN WHICH BEFORE THE WAR THE TERRITORY OF POLAND WAS PARTITIONED.

—	*Russia.*	*Germany.*	*Austria.*	*Poland.*
	1911	1911	1911	1925
1. Length, kilometres (miles)	55 404 (34 427)	58 817 (36 548)	40 970 (25 458)	16 997 (10 562)
2. Passengers, thousands	202 872	1 613 977	384 673	162 604
3. Passenger-kilometres (passenger-miles), millions	24 292 (15 095)	41 706 (25 915)	13 924 (8 652)	6 366 (3 956)
4. Passenger-kilometres per 1 kilometre (passenger-miles per 1 mile) of length.	440 000	709 000	324 000	375 000
5. Average journey, kilometres (miles) . .	120 (74.6)	26 (16.2)	36 (22.4)	39 (24.2)
6. Metric (English) tons, thousands. . . .	244 062 (240 207)	592 531 (583 173)	213 235 (209 867)	58 364 (57 442)
7. Ton-kilometres (English ton-miles) millions	56 251 (34 401)	61 109 (37 372)	24 971 (15 271)	12 209 (7 467)
8. Ton-kilometres per 1 kilometre (English ton-miles per 1 mile) of length: . . .	1 015 000 (999 000)	1 039 000 (1 023 000)	581 000 (572 000)	718 000 (707 000)
9. Average haul, kilometres (miles)	230 (143)	103 (64)	112 (70)	209 (130)
10. Ratio of ton-kilometres to passenger kilometres or English ton-miles to passenger-miles	2.3	1.5	1.8	1.9

This table shews :

— that the density of traffic on the Polish Railways in 1925 exceeded that of the Austrian railways before the War, but was less than that of the German and of the Russian railways.

— that the average passenger journey was greater than that in Germany and in Austria, but less than in Russia.

— that the average freight haul was greater than in Germany and in Austria and nearly equal to that in Russia.

— that the ratio between the passenger and freight traffic was very near that of Germany and of Austria, but remained much below that of Russia.

3. — Rolling stock position.

The following table compares the rolling stock position on the Polish Railways in 1925 with that existing before the War in the States between which the territory of Poland was partitioned :

—	*Russia.*	*Germany.*	*Austria.*	*Poland.*
	1911	1911	1911	1925
1. Locomotives	16 990	27 579	11 105	5 123
per 100 km. . . .	30.7	46.9	25.8	30.1
per (100 miles) . .	(49.4)	(75.5)	(41.5)	(48.4)
2. Carriages.	21 289	62 371	23 447	11 781
per 100 km. . . .	38.4	106.1	54.5	70
per (100 miles) .	(61.8)	(170.7)	(87.7)	(112.6)
3. Wagons	409 338	637 357	252 631	130 932
per 100 km. . . .	73.9	108.4	58.8	78
per (100 miles) . .	(118.9)	(174.4)	(94.6)	(125.5)

This shews that in rolling stock the Polish Railways are only inferior to pre-war Germany. When the traffic is considered it is seen that the Polish Railways had an excess of rolling stock, which is explained by the falling off in traffic in 1925 due to the economic crisis. This excess stock taken out of service and kept in reserve at the stations, at certain periods was as much as 1 300 locomotives and 34 000 wagons. It should be remembered that a large part of the stock, especially of the locomotives received at the distribution of the former German and Austrian stock, was made up of old and worn units.

The percentage of the rolling stock under repair which in 1920 was as much as 42.5 % of the locomotives, 27.3 % of the carriages, and 19.5 % of the wagons, was gradually reduced and at the 31 December 1925 had been brought down to 16.48 % of the locomotives, 18.17 % of the carriages and 9.31 % of the wagons.

The table below gives the same comparison as before of the utilisation of the rolling stock :

—	*Russia.*	*Germany.*	*Austria.*	*Poland.*
	1911	1911	1911	1925
1. Distance run by trains, thousands of kilometres (thousands of miles) :				
a) passenger	141 377 (87 849)	450 381 (279 859)	169 226 (105 154)	53 990 (33 548)
b) freight	211 053 (131 145)	275 926 (171 455)	130 067 (80 821)	37 903 (23 552)
c) total	352 430 (218 994)	726 307 (451 314)	299 293 (185 975)	91 928 (57 122)
2. Average daily number of trains, per kilometre (per mile) :				
a) passenger	7 (11.3)	21 (33.8)	10.8 (17.4)	8.7 (14.0)
b) freight	10.4 (16.7)	12.9 (20.8)	8.3 (13.4)	6.1 (9.8)
c) total	17.4 (28.0)	33.9 (54.6)	19.1 (30.8)	14.8 (23.8)
3. Distance run by axles, millions of kilometres (millions of miles) :				
a) passenger	4 995 (3 104)	8 775 (5 453)	2 957 (1 837)	1 443 (897)
b) freight	15 909 (9 885)	21 646 (13 450)	9 294 (5 775)	3 250 (2 019)
c) total	20 904 (12 989)	30 421 (18 903)	12 251 (7 612)	4 693 (2 916)
4. Average number of axles per train :				
a) passenger	35.3	19.5	17.5	26.1
b) freight	75.4	78.5	71.5	86.3
c) together	59.3	41.9	40.9	51
5. Average number of passengers :				
per train	173	93	82	118
per axle	4.9	4.8	4.7	4.7
6. Average number of metric (English) tons :				
per train	267 (263)	221 (218)	192 (189)	322 (317)
per axle	3.54 (3.48)	2 82 (2.78)	2.69 (2.65)	3.73 (3.67)

These figures shew that the use made of the carriages in Poland in 1925 was almost the same as in Russia, Germany and Austria pre-war, and that the use made of the freight wagons was much better.

4. — Staff.

The staff position is given by the table below :

—	*Russia.*	*Germany.*	*Austria.*	*Poland.*
	1911	1911	1911	1925
1. Total number of employees.	696 000	711 000	408 000	191 572
2. Number of employees :				
per kilometre of line	12.6	12.1	9.5	11.4
(per mile)	(20.3)	(19.5)	(15.3)	(18.3)
3. Number of employees :				
per 10 000 train-kilometres	19.7	9.8	13.6	20.2
(per 10 000 train-miles)	(31.7)	(15.8)	(21.9)	(32.5)
4. Number of employees :				
per 100 000 axle-kilometres	33.3	23.4	33.3	39.7
(per 100 000 axle-miles)	(53.6)	(37.7)	(53.6)	(63.9)
5. Number of employees :				
per 1 000 000 of passenger and ton-kilometres (1)	8.6	6.9	10.5	10
(per 1 000 000 of passenger-miles). .	(13.8)	(11.1)	(16.9)	(16.1)
(per 1 000 000 of English ton-miles) .	(14.1)	(11.3)	(17.2)	(16.4)

(1) Taking 1 passenger-kilometre as approximately equal to 1 ton-kilometre.

This shews that the number of employees on the Polish Railways exceeds that of pre-war in relation to the unit journey of the rolling stock (per 10 000 train-kilometres) : it is lower than that of Austria in relation to the unit of effective work (per 1 000 000 passenger and ton-kilometres) and than that of Russia and Germany in relation to the unit of length of the system (per kilometre).

5. — Financial results.

Comparative situation of 1925 and 1924 :

—	1925	1924
a) Receipts, zlotys (1) :		
1. Passengers	264 939 000	223 235 000
2. Luggage	13 627 000	17 810 000
3. Freight.	543 070 000	476 693 000
4. Various receipts	69 912 000	70 287 000
Total. . .	891 548 000	788 025 000
b) Expenditure, zlotys.	884 571 000	714 330 000
c) Net revenue	6 977 000	73 695 000
d) Co-efficient of operation	99.2	90.7

(1) In 1924, 1 zloty = 1 gold-franc ; in 1925, 1 zloty = on an average 0.89 gold-franc.

—	1925	1924
e) Average receipts :		
a) per passenger-kilometre	0.042	0.033
a) per passenger-mile	(0.068)	(0 053)
b) per ton-kilometre (luggage)	0.586	0.791
b) per English ton-mile (luggage)	(0.958)	(1.293)
c) per ton-kilometre (freight)	0.044	0.043
c) per English ton-mile (freight)	(0.072)	(0.070)

This table shews that the financial results of operation of the Polish Railways in 1925 were less satisfactory than those of the previous year. The receipts increased 103.7 millions, but the expenditure rose by 170.2 millions, reducing the net revenue from 73.5 millions in 1924 to 7 millions in 1925.

After Germany closed its frontiers in July 1925 to the exportation of Polish coal, Poland, by reducing its tariffs appreciably, endeavoured to find new outlets for its coal which, as stated above, was directed towards the Baltic. The increase in the mean haul per ton has undoubtedly had the effect of increasing the receipts, but also of increasing, proportionally more, the corresponding operating costs.

As a matter of fact, the operating results in 1924 and 1925 are not strictly comparable, 52.6 million zlotys having been spent in 1925 in the purchase of new rolling stock in replacement of old condemned stock, no equivalent expenditure having been made in 1924.

The co-efficient of operation in 1925, 99.2 %, compared with that of pre-war, 59 in Russia, 65 in Germany, and 73 % in Austria, appears to be very high, but this is general in all European countries.

In the case of Poland which suffered more severely from the ravages of the war than the other countries, the high co-efficient of operation is due, on the one hand, to the increased costs, and, on the other, to the low freight tariffs.

[385 .1 (.73)]

6. — United States Railway prosperity.

Figs. 10 to 12, p. 724.

(*Bulletin technique de la Suisse Romande.*)

The Railway Companies of the United States of America increased their capital by 3 557 million dollars during the four years 1923 to 1926. During 1926 alone the increase amounted to 875 million dollars, divided as follows :

Locomotives	96 millions.
Wagons	210 —
Carriages	55 —
Other rolling stock	19 —
New lines	174 —
To be brought forward.	554 millions.
Brought forward.	554 millions.
Heavier rails	39 —
New ballasting	18 —
Workshops and locomotive sheds	40 —
Other new works	224 —
	875 million dollars.

Unlike other railway enterprises on which the « cost of construction » is increasing in an alarming manner whilst the tariffs remain excessively high, the American companies have

been able to serve their users at lower rates, as the following table shews :

YEAR.	Receipts per ton-mile (in cents).
1921	1.275
1922	1 177
1923	1.116
1924	1.116
1925	1 097
Mean, 1921-1925	1.149
1926	1.081

That is to say, in 1926 there was a reduction of 15.2 % with regard to 1921; 5.9 % with regard to the mean of 1921-1925 and 1.5 % with regard to 1925.

These satisfactory results have been obtained as the result of the intelligent policy adopted by the companies in order to ensure permanent contact between the public and themselves. In addition, Mr. C. Colson pointed out with much perspicacity in the third edition (1908) of his classic, *Transports et Tarifs :* « The American companies, without asking of the State anything more than liberty of action... have been the principal factor in the amazing rise of an agricultural, industrial and commercial power, which undoubtedly in the near future will be the foremost in the world. »

A penetrating analysis, summed up in tables and diagrams, of the steady improvement in « efficiency » of the United States Railways, will be found in the pamphlet *A Review of Railway Operations in 1926*, by Mr. J. H. Parmelee, Director of the Bureau of Railway Economics at Washington, to whose remarkable works we have already called attention. We have taken the diagrams given below from this paper as being very suitable for shewing the value of the operating methods of a transport undertaking.

Figure 10 shews the increase in 1926 over the average of 1921-1925, of the mean monthly *daily distance run by a goods wagon.* It will be as well to note that this journey is the product of the *number of wagons* × *miles* divided by the *total* number of wagons including those stopped for any reason. If only traffic wagons are taken into account, the mean journey, in 1926, instead of 30.4 miles becomes 35.7 miles.

Figure 11 compares in the same way the *average net train load* and figure 12 the *traffic in tons* × *net train-miles* × *hours.*

The *coal consumed in thousands of tons* × *gross miles* (load plus tare weight of the train including locomotive and tender) has been reduced by 3 pounds in 1926, with regard to 1925 (140 to 137 lb.). This reduction is far from negligible as every pound of fuel saved per 1 000 ton-miles represents a saving of 3.5 million dollars.

* * *

One of the methods that has most efficiently contributed to the progress of railway transport in the United States by assuring the « contact », mentioned above, between the users, and the railways, has been the formation of Regional Advisory Boards. There are 14 of these associations, each covering three to six States of the Union coinciding with the Car Service Divisions of the American Railway Association. These Boards which cover the whole territory of the United States group together more than 15 000 leaders of industry, commerce, agriculture, finance, etc., and represent more than 25 million railway users. By means of Advisory Committees (the Advisory Board of the Atlantic States has more than fifty such Committees) the Boards consider the following matters :

1. Formation of a liaison between the users of the railways, light railways, and carriers in general, represented by the Car Service Division of the American Railway Association with a view to arriving at the best possible understanding of local and general transportation requirements, analysing the transport conditions in each area and assisting the carriers in providing the necessary rolling stock;

2. Investigation into production and distribution of commodities with a view to improv-

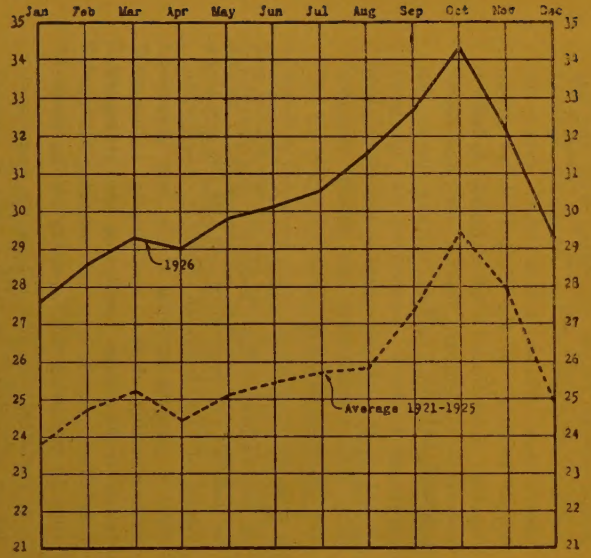

Fig. 10. — Monthly average daily wagon journey.

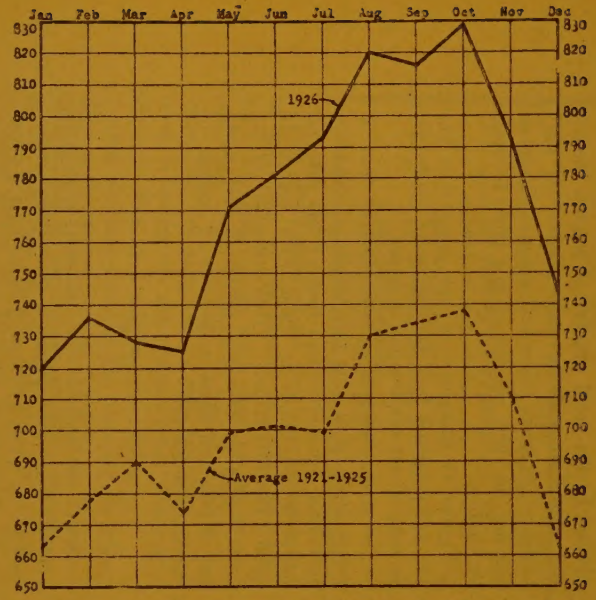

Fig. 11. — Monthly average of net load in short tons per train.

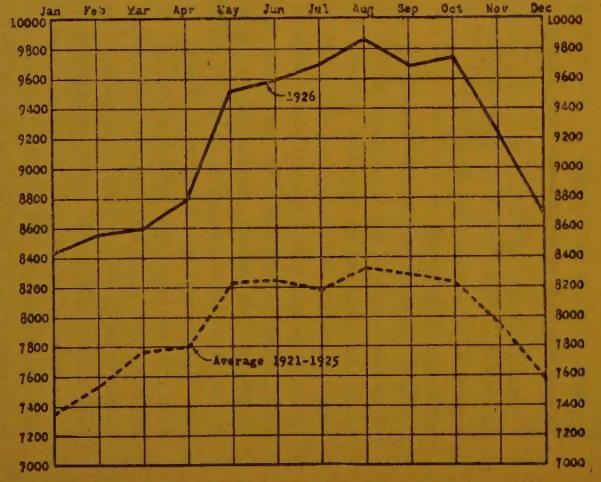

Fig. 12. — Monthly average traffic in ton-miles per train hour.

ing transport and steadying the movement of traffic;

3. Improvement in the use of rolling stock by loading to capacity and by better routeing.

4. Better instruction of the carriers as to the requirements of the public and inciting them how best to satisfy them and, on the other hand, making the users understand the benefits of co-operation and the necessity for observing the principles governing the proper use of the stock;

5. Keeping both the users and the companies informed of traffic conditions in each section so as to ensure a proper allocation of rolling stock throughout the whole country;

6. Smoothing out all disputes that may occur between the carriers and the users;

7. Offering the users a direct means for expressing their opinion on the work of the Car Service Division on matters affecting the public.

* * *

The Americans unanimously congratulate themselves on the services rendered by the Advisory Boards, not only in transportation matters, but in a much wider field, as these Boards have assisted in improving the public economy as a whole by giving quicker circulation to all products, which results in smaller stocks and less money in circulation, whence less immobilisation of these « frozen assets », as the Americans call them.

NEW BOOKS AND PUBLICATIONS

[385 .14 (.54) & 385 .3 (.54)]

MEHTA (N. B.), Ph. D. — **Indian Railways : Rates and Regulations.** — One volume in 8vo (8 7/8 × 5 3/4 inches) of 188 pages. — 1927, London. P. S. King & Son, Ltd., Orchard House, 14, Great Smith Street, Westminster. — Price : 10 sh. 6 d

In his book Mr. N. B. Mehta has produced a useful contribution to the growing library of Railway Economics. It deals with three ages of Indian Railways: the past, which gives a detailed account not only of the historical growth of the railways but also of the attitude of the Government towards railway policy; the present in which the theory of rate-making is considered and the present situation condemned; and the future in which the author expatiates on the urgency of a Rates Advisory Committee and a drastic revision of things in general.

The first two chapters give a lucid and businesslike account of railway development in India in which the author passes on to the reader the results of the considerable research which he has obviously undertaken for the purpose of his book.

In the third chapter Mr. Mehta deals interestingly with the theory of railway rates and emphasises the principles which he considers should be kept in view by those responsible for this all important branch of commercial work in India. The following quotation from this chapter (page 73) is interesting :

« But to judge whether an existing rate « is high or not, a lower rate must be tried « and its effects upon the traffic observ- « ed. So that to declare off-hand that « an existing rate is reasonable because « trade moves out, is unconvincing. The « existing rate may have prevented a « stream of traffic which would have « been impelled by a lower rate. It fol- « lows then that the principle of charg- « ing what the traffic will bear may « be practised so as to exact all that « the traffic will bear. It is thus empir- « ical and affords no norm of what the « charges shall be nor does it provide « for reasonable rates. »

Subsequent chapters deal with the development of « Rates and regulation » and « Competition and rates discrimination » in a most comprehensive manner and the whole field of Indian railway policy is surveyed. Conditions in India are, of course, entirely different from those in Great Britain as we can understand when we find the author stating that competition is not strong enough to regulate rates and therefore the State must take charge.

The book supplies to all who are interested in this subject a well written and lucid monograph on Indian railways, their rates and regulations.

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